PROCEEDINGS OF

THE INSTITUTE

Reports of Council · Meetings · Notices

Autumn General Meeting, 1956

THE AUTUMN GENERAL MEETING OF THE IRON AND STEEL INSTITUTE was held on Wednesday and Thursday, 21st and 22nd November, 1956, at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. The President, Dr. H. H. BURTON, C.B.E., was in the Chair.

Sessions were held from 10.45 A.M. to 1.0 P.M. and from 2.15 to 4.45 P.M. on the Wednesday, and from 10.0 A.M. to 1 P.M. and 2.15 to 4.0 P.M. on the Thursday.

MINUTES OF THE PREVIOUS MEETING

THE MINUTES of the previous meeting, held in London on 16th and 17th May, 1956, were taken as read and confirmed.

PRESIDENT'S REMARKS

Welcome to Members and Visitors

The **President** extended a welcome to all members and visitors attending the meeting. He welcomed particularly members and visitors from abroad, including those from IRSID and USINOR in France.

Obituary

The Institute had suffered the loss by death of a number of members, and he referred particularly to the following: Mr. J. S. Hollings, C.B.E., who joined the Institute in 1903, becoming a Member of Council in 1930, a Vice-President in 1938 and an Honorary Vice-President in 1946; Mr. G. R. Rosevere (elected 1896); Mr. N. D. Ridsdale (elected 1911); Mr. E. Houghton (elected 1905); Mr. H. Shillitoe (elected 1914); Mr. G. W. Green (elected 1917); and Dr. D. Binnie (elected 1927). He also mentioned his own colleague, Mr. Basil Gray, who had recently presented a paper at the Annual General Meeting and in France.

Recent Meetings

The Institute had held a delightful meeting in France in June by invitation of the Société Française de Métallurgie, of which his friend Baron Walckenaer was the distinguished President, and of the Chambre Syndicale de la Sidérurgie Française, whose President was Monsieur J. Raty; both bodies had welcomed them in grand style.

During that meeting, Baron Walckenaer and Dr. E. Dupuy, Past-President and Honorary General Secretary of the Société Française de Métallurgie, had given the Institute the pleasure of accepting election as Honorary Vice-Presidents, and Monsieur Raty and Monsieur H. Malcor, well known in connection with his excellent work for IRSID, had become Honorary Members. Mr. Headlam-Morley and himself had been made Honorary Members of the Société Française de Métallurgie. Dr. Dupuy had recently been elected to the Legion of Honour. He had arranged for congratulations to be sent.

On 12th October a Meeting on Corrosion had been held at the Offices of the Institute, by arrangement with B.I.S.R.A. The Meeting was well attended, and was an excellent example of the value of co-operation between the Institute and the Research Association, to the benefit of the members of both organizations, the industry, and science.

There had been a very successful meeting of the Engineers Group in South Wales on 4th and 5th October. Nearly 250 members attended and the discussions were of a very high order. He thanked all those concerned in arranging the meeting, and particularly the Steel Company of Wales Ltd. for their hospitality.

Council of B.I.S.R.A.

The Council and the Institute were grateful to those members who served as representatives of the Institute on the Council of the British Iron and Steel Research Association. They were Dr. N. P. Allen, F.R.S., Dr. T. P. Colclough, C.B.E., Mr. R. A. Hacking, O.B.E., Mr. N. C. Lake, the Hon. R. G. Lyttelton, Dr. J. G. Pearce, O.B.E., Professor A. Preece, Professor A. G. Quarrell, and Mr. R. L. Walsh.

Publications

He felt that it was appropriate to leave until the Annual General Meeting an extensive review of the past year and plans for the future in this field. The Publications Committee and the Council kept all the Institute's publications constantly under review, and it was proposed to continue essentially on the present lines, which they believed to achieve a suitable balance between perfection and cost; a number of minor but not unimportant improvements would be made in the near future.

The British Foundryman

A particular item worthy of attention was that a new journal called *The British Foundryman* was shortly to be published by the Institute of British Foundrymen. The Institute was pleased to be associated with this. It was felt that this would be of benefit to all those who were interested in iron and steel casting.

Library and Information Department

Another item which was of importance was that they were examining at the present moment, in conjunction with B.I.S.R.A., the services provided by the Library and Information Department in order to effect improvements. However, there was a committee dealing with this, and it was too early yet to make any definite announcement.

Relations with other Societies

Relations with other Societies and Institutes, both at home and abroad, continued to be cordial and friendly, and he proposed to refer to this at greater length at the Annual Meeting.

He congratulated The Institute of Metals on their fine new building in Belgrave Square. They regretted very much that it had been found necessary for the Institute to leave 4 Grosvenor Gardens, but the reasons for doing so had been obvious, since The Institute of Metals had wished to expand. Cordial relations between the Councils, members, and staff remained as ever, and he was sure that all Members would wish the Institute well in their new home.

They were glad to welcome The Institution of Metallurgists back to 4 Grosvenor Gardens. The two bodies had interests in common, and there were about 1150 joint members. All Members would wish The Institution of Metallurgists well in their re-occupation of premises at 4 Grosvenor Gardens.

The arrangements for affiliation with twelve local societies in England and Wales continued to help all parties. There had been a very stimulating meeting on the previous day with their representatives and everybody present seemed to be happy with the existing arrangements.

ANNOUNCEMENTS

The **Secretary** (Mr. K. Headlam-Morley) reported the following changes on the Council since the last General Meeting in May, 1956:

Honorary Vice Presidents: Dr. E. L. Dupuy, Baron Walckenaer.

Vice President: Sir Charles Goodeve, O.B.E., D.SC., F.R.S.

Honorary Members of Council:

Representing Affiliated Local Societies:

Mr. F. B. George, President of the Cleveland Institution of Engineers, to succeed Mr. H. H. Utley.

Mr. W. H. R. Bird, President of the Ebbw Vale Metallurgical Society, to succeed Mr. J. F. Smith.

Mr. A. Lenton, President of the Leeds Metallurgical Society, to succeed Mr. C. Breckon.

Mr. C. T. Thomas, President of the Lincolnshire Iron and Steel Institute, to succeed Lt. Cdr. G. W. Wells.

Mr. W. Rose, President of the Liverpool Metallurgical Society, to succeed Mr. C. T. Callis.

Mr. G. A. Cottell, President of the Manchester Metallurgical Society, to succeed Mr. C. J. Bushrod.

Mr. A. Biddulph, President of the Staffordshire Iron and Steel Institute, to succeed Mr. K. G. Lewis.

Mr. R. Walker, President of the Swansea and District Metallurgical Society, to succeed Mr. R. W. Evans.

Representing B.I.S.R.A.

Mr. W. C. F. Hessenberg, Deputy Director.

Retiring Members of Council:

The following were due to retire at the next Annual General Meeting and were eligible for re-election:

Vice-Presidents: Mr. C. R. Wheeler, C.B.E., Mr. D. F. Campbell, and Mr. G. H. Latham.

Members of Council: Mr. S. Thomson, Mr. E. T. Judge, Mr. E. J. Pode, Mr. B. Chetwynd Talbot, and Mr. W. L. James.

Andrew Carnegie Scholarship

The following award had been made since the last General Meeting:

£400 (2nd Grant) to J. W. BARTON (Liverpool University). To assist research on "The Use of Paraffin Wax to Simulate Strain Patterns during Plastic Deformation of Metals."

Dates of Meetings in 1956 and 1957

Annual General Meeting in London on Wednesday and Thursday, 22nd and 23rd May, 1957. *Dinner for Members* on Wednesday, 22nd May.

Special Meeting in Sheffield, during the week beginning 8th July, 1957.

Autumn General Meeting in London on Wednesday and Thursday, 20th and 21st November, 1957.

Meetings of the Engineers Group:

5th December, 1956: Meeting at 4 Grosvenor Gardens at 10.30 a.m. on "Blowers for Use in Iron and Steel Works" and "Gas and Air Compressors."

25th and 26th September, 1957: Papers on "Air Polution"; 11th and 12th December, 1957: Papers on "Water Pollution" (both probably at Church House, Westminster, S.W.1).

Joint Group on Powder Metallurgy

The Councils of The Iron and Steel Institute and of the Institute of Metals had decided to form a Joint Group on Powder Metallurgy, to operate within the existing framework of the two Institutes.

NOMINATION OF PRESIDENT

The **President** said that it was customary for the President to be nominated by the Council and for that nomination to be announced and confirmed at the Autumn

General Meeting, after which the President was duly elected at the Annual General Meeting in May. After considerable thought, the Council had nominated Mr. Arnold H. Ingen Housz, of the Royal Netherlands Blast Furnaces and Steelworks Ltd., whom many of them had met both in this country and in Holland and whom they all knew to be a delightful and able man.

It was only rarely that they elected as President a member from outside Great Britain, but this had been done so three times in the past, the last occasion being almost forty years ago. Many of them thought that it was in keeping with the international colouring which was a very important feature of the Institute that they should now and again have a President from abroad, especially so distinguished a President as their nominee on this occasion, Mr. Ingen Housz. Mr. Ingen Housz had been a Member of the Institute for many years and had been for several years an Honorary Vice-President. He therefor had great pleasure in nominating Mr. Ingen Housz.

Mr. **J. Mitchell,** C.B.E., seconded the proposal, which was carried unanimously.

ELECTION OF MEMBERS

Mr. **Geoffrey Poole** and Mr. **N. D. Thomson,** who had been appointed scrutineers of the ballot, reported that the following had been elected:

Members

Akerhielm, Kjell (Degerfors, Sweden); **Ayton,** Stanley (London); **Barlow,** John William (Birmingham); **Benson,** Ronald Carey, M.C., B.ENG. (Darlington); **Betney,** Robert, A.M.C.T., L.I.M. (Bolton); **Blain,** Paul (St-Germain-en-Laye, France); **Bouchier,** Gordon, A.MET., A.I.M. (Sheffield); **Bowness,** Joseph (Scunthorpe); **Bowns,** Eric, A.M.I.MECH.E. (Rotherham); **Brace,** Gordon, M.SC. (Sheffield); **Brunner,** John M., B.MET.ENG. (Canton, Ohio, U.S.A.); **Bullimore,** Eynon Russell (Porthcawl); **Charlier,** Professor Emile G. H. (Angleur, Belgium); **Cherry,** George Joseph Nall, B.SC. (Birmingham); **Clements,** John (Hereford); **Copp,** W. F. (Wheeling, W.Va., U.S.A.); **Crooks,** Robert Nicholas, A.C.T., L.I.M. (Southall); **Danko,** Joseph C., M.S., PH.D. (Pittsburgh, Pa., U.S.A.); **Das Gupta,** Benoyendu, B.SC. (Duisburg, Germany); **Davis,** Cecil Vincent (Stoke-on-Trent); **de Juniac,** Baron Octave, B.SC. (London); **Dilley,** William George (Cardiff); **Dobson,** John Dennis (London); **Donohue,** John Malcolm Keith, M.A. (London); **Dornin,** George A., Jr., B.S. (Sharpsville, Pa., U.S.A.); **Drijver,** Alexander (Ijmuiden, Holland); **Easterbrook,** Arthur Thomas, G.I.MECH.E. (London); **Exley,** John Stanley (London); **Fletcher,** John Thomas (Gateshead); **Fox,** Kenneth McLean, A.M.I.E.E. (Swansea); **Gale,** Walter Keith Vernon (London); **Gostisa,** Nikola, DIPL.ING. (Zenica, Yugoslavia); **Grgic,** Slavko, B.SC. HONS.(MET.) (Zenica, Yugoslavia); **Guard,** Ray W., M.S.(MET.), PH.D. (Schenectady, N.Y., U.S.A.); **Gupta,** Asoka, M.SC., PH.D. (Burnpur, India); **Hammerton,** Derek C. (Scunthorpe); **Hargreaves,** William Denis, M.SC., PH.D. (Sheffield); **Harrison,** George, J.P., A.M.I.MECH.E. (Dudley); **Hart,** Eric Cleaton (London); **Hensler,** John Howard, B.MET.E. (Carlton, Victoria, Australia); **Herrero Egaña,** Francisco (Bilbao, Spain); **Hickman,** George Donald (King's Lynn); **Hirsch,** Sverre P.V., DR.ING. (Mo-i-Rana, Norway); **Hopkins,** Edward Neill (London); **Ishihara,** Yoshio (Kamakura-city, Japan); **Jarman,** Raymond Arthur, L.I.M. (Sidcup); **Jauregui,** Juan José de (St-Germain-en-Laye, France); **Kaku,** Rinjiro (Tokyo, Japan); **Kapetanovic,** Kemal, DIPL.ING. (Zenica, Yugoslavia); **Langenberg,** Frederick Charles, M.S., PH.D. (Pittsburgh, Pa., U.S.A.); **Lohse,** Robert M., B.S. MET.ENG. (Titusville, Pa., U.S.A.); **Mann,** Douglas (Basildon); **Martin,** George William (Brentford); **Mead,** Kenneth (Bristol); **Meetham,** Geoffrey William, B.SC.HONS.(MET.) (Derby); **Melvill,** M. L., B.A., B.SC. (Johannesburg, South Africa); **Nakamura,** Saburo, B.ENG. (Sendai, Japan); **Oxley,** William (Rotherham); **Palm,** Johan (Österbybruk, Sweden); **Peake,** Harald, M.A. (London); **Pearson,** Arthur Edward (Middlesbrough); **Peled,** Abraham, B.SC.(ENG.), DIPL.ING., A.R.T.C. (Haifa, Israel); **Pike,** Terrence Cobden, B.SC. (London); **Profit,** Robert (Paris, France); **Rae,** Dennis Malcolm, B.SC., A.I.M. (Malta, G.C.); **Rakshit,** Subodh Ranjan, B.SC., B.MET. (Duisburg, West Germany); **Ramaswami,** B., B.SC.(HONS) (Ambarnth, India); **Ramaswamy,** L. (Calcutta, India); **Russell,** James Fisher Scott, M.A., B.LITT. (London); **Sankey,** Geoffrey Baldwin, M.A. (Wellington); **Schier,** Pavel Omar (Prague, Czechoslovakia); **Schutz,** Franz, DR.ING.EH. (Düsseldorf-Oberkassel, Germany); **Seybolt,** Alan Upson, B.SC., PH.D. (Schenectady, N.Y., U.S.A.); **Shanks,** Alexander (Glasgow); **Smith,** Harold Sydney, L.I.M. (Acton); **Smith,** Jack Donald (London); **Smithson,** Albert, ASSOC.ENG. (Crayford); **Stanley,** James K., B.S., PH.D. (Pittsburgh, Pa., U.S.A.); **Stanworth,** Alfred John (Scunthorpe); **Steer,** John Leslie, B.MET., L.I.M. (London); **Stevens,** Gerald Henry, L.I.M. (Middlesbrough); **Stryker,** Robert S., B.S.MET.ENG. (Bridgeville, Pa., U.S.A.); **Taylor,** Tom Rough (Glasgow); **Testero,** Dott. Giuseppe (Milan, Italy); **Thomas,** Arthur Guest (Llanelly); **Thomson,** John, M.A., D.SC., PH.D., M.I.E.E., F.INST.P. (Chislehurst); **Villamil,** Ramon Diaz Lopez (Gijon, Spain); **Villers,** Jean (Brussels, Belgium); **Wahlsteen,** Axel Olof (Bofors, Sweden); **Wallhead,** Alfred Victor (Consett); **Walters,** Archibald Francis, M.B.E., M.I.MECH.E., M.I.LOCO.E. (London); **Weibull,** Ivar (Tannefors, Sweden); **Weitlauf,** Frederica M. (East Chicago, Ind., U.S.A.); **Widmer,** Maurice (Le Bourget, France); **Willey,** John Matthew, A.M.I.E.E., M.I.I.A., M.INST.W. (Waltham Cross); **Wilson,** William, Jr., M.S. (Chicago, Ill., U.S.A.); **Winston,** John Stanton, M.A., M.SC.MET.ENG. (Reno, Nev., U.S.A.); **Yates,** Leonard (Sheffield); **Yoshizaki,** Kozo, DR.ENG. (Tokyo, Japan).

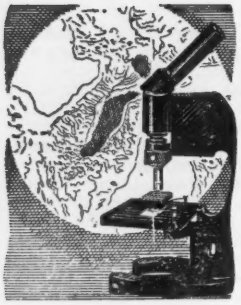
Associate Members

Adderley, David J. (Birmingham); **Allday,** William John (Cambridge); **Andrews,** Charles Clifford (Cambridge); **Ayres,** Alan Geoffrey (Darlaston); **Bagshaw,** Norman Ernest (Cambridge); **Bainbridge,** John Evelyn (Chesterfield); **Beaumont,** Ralph (Halifax); **Blankenburgs,** Gunars (Newcastle-on-Tyne); **Crawford,** William McLay (Glasgow); **Farmer,** E. B. (Birmingham); **Farmer,** Raymond Cedric, L.I.M. (Birmingham); **Farrow,** Michael (Chesterfield); **Filby,** John David (Birmingham); **George,** P. M. (Cambridge); **Grantham,** Derek Keeling (Newcastle-on-Tyne); **Halford,** Frank Bastin (Newcastle-on-Tyne); **Harbach,** Arthur John (Sheffield); **Harrison,** William (Swansea); **Hayhurst,** Anthony (Sheffield); **Hedley,** James Armstrong (Newcastle-on-Tyne); **Hedley,** Raymond (Newcastle-on-Tyne); **Hunton,** John Scott (Newcastle-on-Tyne); **Jackson,** Peter Woodall (Cambridge); **Keeble,** John G. (Cambridge); **Kelly,** Patrick Manning (Cambridge); **Lunzer,** Raphael Alan, B.SC.(ENG.MET.) (London); **Marsh,** David John (Birmingham); **May,** Michael John (Sheffield); **Moore,** Nigel Edward Sidney George (Swansea); **Nancarrow,** Donald John Francis (Cardiff); **Phillips,** Edryd (Cardiff); **Pope,** John Frederick, B.A. (Cambridge); **Price,** Christopher Eric (Swansea); **Redstone,** Seymour Ivor (Cambridge); **Ridal,** Kenneth Arnold (Sheffield); **Rowe,** Alan David (Swansea); **Rudge,** Cyril Godfray George (Cambridge); **Seebohm,** Richard Hugh (Cambridge); **Starks,** David Ernshaw (Cambridge); **Toussaint,** Friedrich J. (Berlin, Germany); **Towner,** Jeremy Michael (London); **Varley,** Robert (Cambridge); **Walker,** Brian (Birmingham); **Walter,** P. F. (Cambridge); **Willans,** Gordon Ralph, A.MET. (Sheffield).

The **President** declared these candidates to be duly elected. They numbered 144, and the total membership of the Institute was now 5088, which was a record figure for the Institute.

PRESENTATION OF PAPERS

A list of the papers presented and discussed at the Technical Sessions of the Autumn General Meeting appeared on p. 348 of the November, 1956, issue of the *Journal*. Reports of the discussions will be published later in 1957.



PAPERS AND REPORTS ON RESEARCH AND PRACTICE

Metallurgy · Plant Operation · Research

The Strain Ageing of Boron-treated Low-Carbon Steels

By E. R. Morgan and J. C. Shyne

SYNOPSIS

The efficiency of boron additions and commercial box annealing in suppressing nitrogen and carbon strain ageing in alloys of commercial composition has been investigated. The results show that for all practical purposes boron-treated, box-annealed, low-carbon steels containing 0·007–0·02% boron are non-ageing. Consideration of economics, ingot segregation, and boron–oxygen equilibrium shows that for rimming grade open-hearth steel the most promising level of boron additions is in the region of 0·007%.

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STRAIN AGEING in steel is the name given to time-dependent changes which occur in the properties of the cold-worked material during storage. These changes are readily observed experimentally through a study of mechanical properties.

The effects of strain ageing are usually regarded as being detrimental, particularly in deep-drawing steels. For example, an increase in yield strength and loss in ductility during ageing lead to buckling and tearing during drawing. At the same time, the return of the sharp yield point results in the formation of Lüders bands or stretcher strains during the pressing operation.

As a result of these effects many attempts have been made to eliminate strain ageing from commercial low-carbon steel. However, the practical problem still remains because all known methods of preventing strain ageing result in a more costly steel.

Manuscript received 3rd August, 1956.

Mr. Morgan is Assistant Director of Research with the Jones and Laughlin Steel Corporation, Pittsburgh, Pennsylvania, and was formerly associated with Ford Motor Company, Dearborn, Mich., U.S.A.; Mr. Shyne is Research Engineer at the Metallurgy Department of the Scientific Laboratory, Ford Motor Company, Dearborn, Mich., U.S.A.

The aim of the present work was to examine the feasibility of boron additions to eliminate strain-ageing caused by nitrogen in alloys of commercial composition.

PREVIOUS WORK

The most satisfactory theory of strain-ageing is that due to Cottrell.[1] This theory suggests that strain ageing may be regarded as the migration of interstitial atoms to free dislocations, and the anchoring of those dislocations by the resulting atmosphere formation. The activation energies for strain ageing of alpha-iron correspond to those for the diffusion of carbon and nitrogen, and the time required for strain ageing is controlled by the rate of migration of the interstitials. It may be concluded that the important

Table I

ANALYSES OF ALLOYS WITH HIGH NITROGEN CONTENT

Alloy	C, %	N, %	O, %	B, %	Mn, %
H_0	0·07	0·004	0·003	0·000	0·56
H_5	0·06	0·005	0·004	0·005	0·55
H_7	0·06	0·005	0·004	0·007	0·56
H_9	0·06	0·005	0·005	0·009	0·56
H_{13}	0·06	0·006	0·008	0·013	0·54
H_{20}	0·06	0·006	0·007	0·020	0·56
H_{25}	0·07	0·005	0·006	0·025	0·55
H_{30}	0·06	0·007	0·006	0·030	0·56

factor which governs the degree of strain ageing in a given storage time at room temperature is the effective amount of carbon and nitrogen in solution.

The only economic way to reduce the amount of carbon in solution is by heat-treatment. Commercial box-annealing (Fig. 1)—heat-treatment which comprises slow heating, annealing, and slow cooling—is not by itself enough to eliminate carbon strain ageing in high-purity Fe–C alloys.[2] The prolonged quench-ageing treatment necessary to remove carbon strain ageing[3] is too expensive for use in the preparation of deep-drawing sheet steel. Removal of carbon from solution should be facilitated by the addition of relatively small amounts of weak carbide-forming elements.[4] The presence of chromium as a residual element in commercial low-carbon steel probably assists in the avoidance of carbon strain ageing.

In commercial steels nitrogen is the more important cause of strain ageing because nitrogen is not sufficiently precipitated by commercial heat-treatments to eliminate subsequent strain ageing. Manganese, which is always present in commercial steel, further retards[5] nitrogen precipitation so that all of the 0·004% nitrogen content of open-hearth steels may be in solution after annealing. The precipitation of nitrogen by the addition of strong nitride-forming elements such as titanium[6] or aluminum has the disadvantage that it requires that the steel be killed. The decreased ingot-to-slab yield of killed steels as compared with rimmed steels means that killed steel is intrinsically more costly.

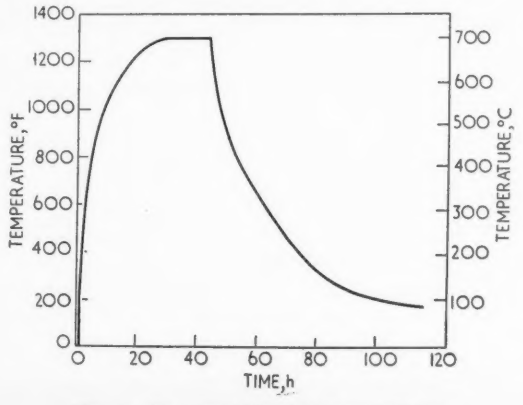

Fig. 1—Box-annealing heat treatment

Table II

ANALYSES OF ALLOYS WITH LOW NITROGEN CONTENT

Alloy	C, %	N, %	O, %	B, %	Mn, %
L_0	0·06	0·003	0·009	0·000	0·56
L_7	0·06	0·004	0·010	0·007	0·52
L_9	0·06	0·003	0·005	0·009	0·50
L_{12}	0·07	0·004	0·006	0·012	0·55

Vanadium is effective in eliminating nitrogen strain ageing from rimming steels, but is too expensive an alloying addition. Morgan and Shyne[2] have demonstrated that boron, which also is not a strong deoxidizer, can be effective in eliminating nitrogen strain ageing from quench-aged high-purity Fe–C–N alloys.

The effectiveness of boron in eliminating nitrogen strain ageing from box-annealed steel has not been unequivocally established because of the masking effect of carbon strain ageing. The object of the present work was to demonstrate the effectiveness of boron treatment and box-annealing in eliminating both nitrogen and carbon strain ageing in steels containing commercial residual elements. There was the possibility that boron might interact with manganese, chromium, or other elements present in the steel and not be available to tie up the nitrogen.

ALLOY PREPARATION

Two series of alloys were prepared by melting commercial low-carbon rimmed steel in stabilized zirconia crucibles under an atmosphere of helium and nitrogen. The general impurity level of the melting stock and the final alloys was:

P, %	S, %	Si, %	Cu, %	Ni, %
0·009	0·024	0·01	0·06	0·05

Cr, %	Mo, %	Sn, %	Al, %
0·06	0·01	0·01	0·01

Additions of graphite and ferromanganese were made to the melts to raise the carbon and manganese contents to the desired levels. The first series of alloys (Series *H*, Table I) contained 0·005–0·006% nitrogen and 0·000–0·030% boron. This nitrogen level was considered the maximum to be expected in commercial open-hearth steel. The second series of alloys (Series *L*, Table II) contained more conservative amounts of nitrogen and boron, 0·003–0·004% and 0·000–0·012% respectively.

The manganese and chromium contents of the alloy series *H* and *L* both deliberately exceeded typical levels in commercial deep-drawing steel in order that any deleterious interaction between these elements and boron would be maximized.

Table III

ANALYSES OF ALLOYS PREPARED FROM ELECTROLYTIC IRON

Alloy	C, %	N, %	O, %	B, %	Al, %
E_0	0·07	0·005	0·009	0·000	...
E_{20}	0·07	0·006	0·010	0·020	...
E_{Al}	0·08	0·004	0·009	...	0·06

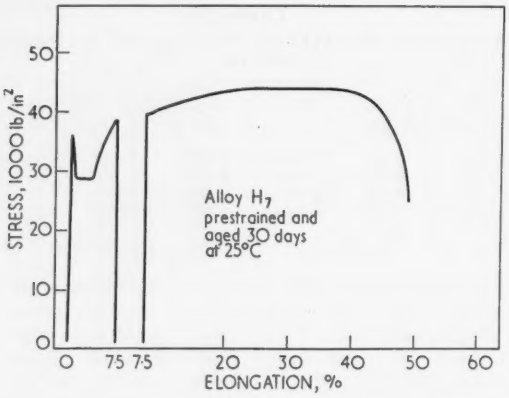

Fig. 2—Tensile-test curve for strain-aged alloy

A further series of alloys was similarly prepared from electrolytic iron (Plast Iron *A*101) such that no single impurity exceeded 0·01%. These alloys (Series *E*, Table III) contained 0·004–0·006% nitrogen.

All of the alloys were chill-cast as 2½-in. dia. ingots and hot-rolled at 982° C (1800° F) to ⅞-in. bars. After final cold-rolling to ⅝-in. rounds, the material was machined into standard A.S.T.M. 0·250-in. tensile samples. Box-annealing (Fig. 1) was carried out in helium at 705° C (1300° F) for 15 h.

EXPERIMENTAL RESULTS

The box-annealed samples of all alloys were prestrained 7½% in tension at a strain rate of 0·03 in./in./min while the load/extension curves were recorded autographically. The load divided by the initial cross-sectional area was regarded as the stress. A prestrain of 7½% was always sufficient to exceed the yield-point elongation and ensure a homogeneously strained sample.

Prestraining was immediately followed by ageing either at room temperature or 100° C. Upon the completion of ageing, the samples were pulled in tension to failure.

Previous work[2] had indicated that the increase in yield stress caused by ageing, called the *ageing index*, is a sensitive and reliable criterion of ageing. This property, together with aged yield strength, ultimate tensile strength, and total elongation, is given in Table IV.

The accuracy of the stress values given is largely dependent upon the accuracy of resetting the tensile load indicator. All stress values are believed to be within ± 300 lb/in² and total elongations within ± 3%.

Typical stress/strain curves for alloys prestrained and aged 30 days at room temperature are shown in Figs. 2 and 3.

Examination of the microstructures of the alloys showed that a boron addition increases the amount of carbide without apparently producing a precipitate of iron boride, and has no effect on the grain size. All samples possessed a grain size of A.S.T.M. 7–8.

DISCUSSION

The ageing index of the base composition alloys in each series, H_0, L_0, and E_0, was markedly reduced by the addition of boron. A maximum effect was observed in the range 0·007–0·025% boron.

In the alloy series *E* the ageing of alloy E_0 was severe as shown by a large ageing index, a rise in U.T.S., and a sharp fall in ductility. This ageing was reduced considerably by the addition of boron or aluminum, but these additional elements did not completely eliminate the ageing. The remaining ageing might well have been caused by carbon which had remained in solution after the box-anneal.

The effect of residual elements in steel of commercial composition is illustrated by a comparison of the ageing characteristics of alloys E_{20} and H_{20} or alloys E_0 and H_0. In both cases the only essential difference between corresponding *E* and *H* alloys was in the amounts of residual impurity elements. The *H* series alloys showed considerably lower ageing tendency than the corresponding *E* series alloys. It seems reasonable to assume that the weak carbide-forming elements, present as impurities in the *H* series, would have encouraged carbon precipitation during the cooling cycle of the box anneal and thus reduced the strain-ageing potential of the alloys. Boron and aluminum should also assist in reducing strain ageing due to carbon. The compounds formed between nitrogen and boron, aluminum and nitrogen, or iron and boron could, if present at relatively high temperatures, act as sites for nucleation of carbides.

Nicholson[8] has shown that both boron, and boron plus nitrogen, dissolve in iron carbide. This phenomenon can account for the observation that those steels which contained boron exhibited a greater amount of carbide and no obvious precipitated particles of iron boride.

The effectiveness of boron in suppressing nitrogen strain ageing does not appear to have been reduced by the presence of residual impurity elements. It is interesting to observe that large amounts of boron, as in alloys H_{25} and H_{30}, led to an increase in the ageing index. The present results show that there is, however, no reason to fear that reasonable boron additions will lead to strain ageing in commercial low-carbon steels.

When the ageing index was below 3500 lb/in² there was no observable yield point. The reason for this

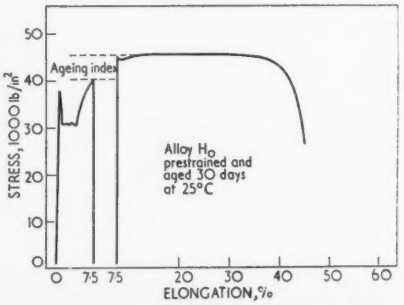

Fig. 3—Tensile-test curve for strain-aged alloy

Table IV

STRAIN AGEING RESULTS FOR ALLOYS BOX-ANNEALED AT 705° C PRESTRAINED 7½% AND AGED

Alloy	Property	Ageing Condition			
		Unaged	7 days at 25° C	30 days at 25° C	1 h at 100° C
H_0	Yield strength, lb/in²	38,550	43,500	45,700	44,450
H_5		37,900	41,750	43,950	43,300
H_7		37,000	37,200	39,300	38,700
H_9		37,000	38,000	38,300	38,950
H_{12}		35,600	37,600	37,100	36,650
H_{20}		38,100	39,000	39,400	39,250
H_{25}		36,950	...	39,700	38,650
H_{30}		36,300	...	41,000	39,450
L_0		36,400	39,250	42,400	42,000
L_7		36,000	36,000	37,250	37,300
L_9		36,550	37,350	37,250	36,400
L_{12}		36,700	37,050	36,750	36,350
E_0		30,550	39,300	41,100	40,200
E_{20}		29,600	32,000	32,200	31,900
E_{Al}		31,200	33,500	32,800	34,250
H_0	Ageing index, lb/in²	...	4100	5200	6150
H_5		...	2350	4750	5700
H_7		...	300	900	1500
H_9		...	0	100	1750
H_{12}		...	500	700	1450
H_{20}		...	300	200	750
H_{25}		...	...	1300	1650
H_{30}		...	...	3400	3050
L_0		...	3150	6050	5550
L_7		...	900	1050	1400
L_9		...	450	900	700
L_{12}		...	850	750	650
E_0		...	8100	9200	9000
E_{20}		...	1500	2950	2100
E_{Al}		...	1100	1700	1800
H_0	Ultimate strength, lb/in²	45,400	45,550	46,100	47,800
H_5		43,900	44,300	45,300	44,350
H_7		43,100	43,100	43,800	43,500
H_9		43,800	43,400	43,400	43,800
H_{12}		42,100	41,900	41,850	42,000
H_{20}		44,300	44,500	44,900	45,400
H_{25}		42,900	...	43,900	43,900
H_{30}		42,700	...	43,000	43,400
L_0		42,600	43,000	43,100	44,700
L_7		42,300	41,800	42,700	42,800
L_9		42,900	43,400	42,900	43,700
L_{12}		42,800	43,000	42,750	42,500
E_0		37,750	44,300	44,550	44,300
E_{20}		37,350	36,750	37,050	37,000
E_{Al}		38,350	38,800	37,800	38,900
H_0	Total elongation, % on 1 in.	49	48	46	44
H_5		51	47	46	47
H_7		53	52	49	53
H_9		53	52	50	52
H_{12}		52	51	50	53
H_{20}		50	50	46	51
H_{25}		48	...	43	46
H_{30}		47	...	43	45
L_0		49	50	49	47
L_7		50	51	51	50
L_9		51	51	51	51
L_{12}		50	51	51	50
E_0		52	40	40	43
E_{20}		56	56	56	56
E_{Al}		54	53	53	53

is not clear, although it could be simply that the specimen alignment was not sufficiently refined in the present experiments. The effects of misalignment in masking the yield point are well known, and the weaker the yield point the more important will be the effects of superimposed bending stresses.

As Cottrell[9] pointed out, even though a sample is stressed below its macroscopic upper yield strength, there will be a premature release of dislocations under the effects of stress concentrations and thermal fluctuations. If this early spread of yielding is to be prevented, it is necessary that obstacles to dislocation

movement should exist. These obstacles may be grain boundaries or even precipitate particles. Consequently, the ease with which a true yield point is observed should depend upon the extent of the obstacles to premature yielding. Thomas and Leak[10] have shown that the ageing index increases progressively on ageing, even though the amount of carbon and nitrogen diffusing to the dislocations apparently has long exceeded the amount required to produce Cottrell atmospheres. The extra supply of interstitials could well be precipitating and simply facilitating the observation of the true Cottrell yield effect. According to this hypothesis, even a sample which contained enough interstitials in solution to form Cottrell atmospheres on ageing might not show a sharp yield point. Where the amount of interstitials exceeded this amount and precipitation also occurred on ageing, a yield point should be observed. The greater the precipitation the greater should be the magnitude of the observed yield point.

The absence of the yield point means that Lüders bands would not be observed for these lower ageing indexes. Similarly, sheet steel with these characteristics should not display stretcher strains when pressed into parts. On this basis, all commercial steels containing between 0·007% and 0·02% boron should be 'non-ageing' when used in deep-drawing operations after prolonged storage.

The gross ageing displayed by alloy E_0 was associated with a severe loss of ductility. Boron additions removed this deleterious effect. The initial ductility of annealed samples was also increased by boron additions with a maximum effect in the alloys H_9 and L_9. Although the overall ductility is not always important it can be the predominant factor in some drawing operations. For example, in the deep-drawing of many present-day automobile body parts, any loss of ductility can lead to excessive scrap losses. The beneficial effects of boron additions should be important in such operations.

From the viewpoint of ageing alone, the optimum range of boron additions appears to be 0·007–0·02%, but both the marked segregation tendency of boron[11] and the economy of the process dictate that the actual additions should be on the low side of the range.

One further important consideration which might control the practical level and mode of boron additions is the interaction between boron and oxygen in the steel. According to data published by Derge,[12] a boron content of 0·02% could exist in equilibrium in molten steel with only 0·022% oxygen. Unfortunately, vigorous rimming would not occur in low-carbon steels of this oxygen content.

The normal 0·06% carbon steel will rim satisfactorily when it contains more than about 0·045% free oxygen.[13] That amount of oxygen should exist in equilibrium with only 0·007% boron in molten steel.[12] For this reason, the most promising level of boron addition for open-hearth steel appears to be about 0·007%. At this level of boron, it should be possible to produce low-cost rimming, chemically-capped, or semi-killed steels, which are not susceptible to strain ageing.

Acknowledgments

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The Structure, Deformation, and Fracture of Pearlite

Part I—STRUCTURE

By K. E. Puttick

SYNOPSIS

Some features of pearlite structure revealed by electron microscopy are described and discussed. These include (i) a fine precipitate in the ferrite, formed after an ageing treatment, of dimensions and spacing approximately 100Å, (ii) inhomogeneity in the cementite shown by the rimmed appearance of etched lamellæ, (iii) branched crystallization of cementite, (iv) linear discontinuities in the lamellar pattern, (v) bent and curved plates of cementite within a colony, (vi) rod-like growth of cementite, (vii) growth of cementite round inclusions. 1190

Introduction

A STUDY OF the effect of plastic deformation on the microstructure of pearlitic steel is at present in progress at the University of Bristol. In the course of this, it was necessary to make a survey of the undeformed structure that was rather more detailed than any previously reported, some results of which appeared to be of sufficient interest to warrant separate publication. These are described in Part I of the present paper; the main investigation, that of the deformation process, is the subject of Part II (p. 167).

The observations are relevant to two aspects of the pearlite problem:

(*a*) The composition of ferrite and cementite

(*b*) Morphology of the cementite lamellæ.

The latter topic is of importance in the disputed field of pearlite growth.

Facts and theories of the transformation of austenite to pearlite have been reviewed by Hull and Mehl,[1] from whose discussion it seems certain that the pearlite colony develops mainly by edgewise growth, the necessary conditions being maintained by diffusion at the pearlite/austenite interface, either within the austenite or along the phase boundary. This process has been analysed by Brandt[2] and Zener.[3] The following points, however, are still controversial:

(i) *The orientation of the lamellæ.* G. V. Smith and Mehl[4] attempted to establish the existence of a habit plane for pearlite, but without success, though the results indicated that if such a habit exists it does not involve a low index plane of austenite. C. S. Smith[5] has, however, suggested that pearlite nucleated at a grain boundary will grow in a grain adjacent to that which determines its orientation, on the grounds that the diffusion conditions for growth cannot be maintained at the coherent interface which the colony would have with its parent crystal. It seems that there is no very strong Widmanstätten tendency in the growing colony, since, as Mehl pointed out, lamellæ grow across austenite grain and twin boundaries without change of direction.

(ii) *Curvature of lamellæ.* Several possible hypotheses were advanced by Mehl to account for the fact that curved cementite plates are frequently observed. Among these were (*a*) transformation stresses, acting either directly to produce buckling of the initially straight cementite,[6] or indirectly by displacing the pearlite/austenite interface; (*b*) attempts by the growing lamellæ to maintain their edges perpendicular to the interface; (*c*) non-uniform carbon distribution produced by the presence of inclusions or other agents. None of these explanations, however, had at the time the support of any substantial evidence.

(iii) *Maintenance of lamellar spacing during growth.* Zener[3] has pointed out that a characteristic spacing during growth must be imposed by surface-energy considerations, but did not particularize any mechanism by which this spacing might be maintained. Mehl, following earlier workers, held that marked departure of inter-lamellar spacing from the critical value would slow up growth by changing the concentration conditions at the interface, and eventually lead to nucleation of new ferrite or cementite which would restore the spacing to the value necessary for growth to proceed. C. S. Smith[5] advanced an alternative possibility: that the spacing is maintained by branched crystallization of cementite, which allows development of the colony without formation of a fresh area of incoherent interface, a process which requires considerable free energy. If this is the mechanism by which the colony develops laterally and maintains the spacing, the cementite must exist in the form of systems of interconnected sheets in the ferrite matrix rather than as isolated plates. Some observations of Smith and Nutting[7] on cementite extracted from pearlite suggest that this is not always the case. The hypothesis is nevertheless an attractive one; Morrogh,[8] following Bunin *et al.*,[9] has explained some of the properties of flake-graphite cast irons in terms of a structure of interconnected graphite within the eutectic cell, and it appears to be an important concept in other types of eutectic and cellular precipitation.

Most of the experimental evidence on which current discussions of pearlite precipitation are based is that of optical micrographs. The present results have been obtained both by optical and electron microscopy, chiefly the latter.

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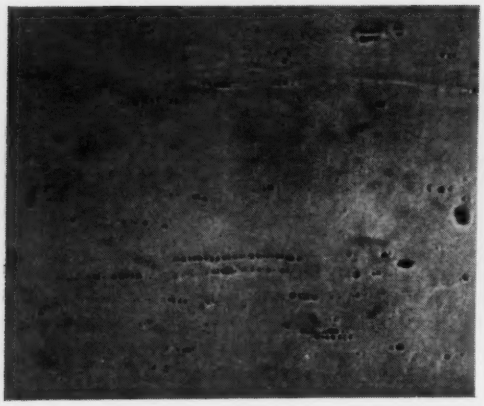

Fig. 1—Electropolished surface of pearlite specimen, showing rows of inclusions. Optical photograph × 180

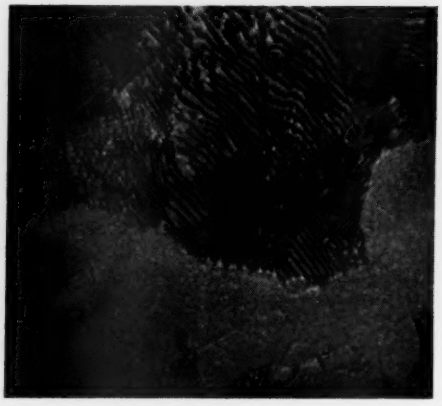

Fig. 2—Pearlite, electrolytically etched in chromic acid, showing deviation of lamellar orientation, and area of free ferrite with mottled texture indicating submicroscopic precipitate. Optical photograph, oblique illumination × 1700

EXPERIMENTAL PROCEDURE

Heat-Treatment and Surface Preparation

The material used in these experiments is EN42, a plain carbon eutectoid steel, supplied from the stock of research steels of the British Iron and Steel Research Association in the form of ½-in. square bars. The following analysis was supplied by the Association:

Composition, %

C	Si	Mn	S	P	Ni	Cr	Mo
0·78	0·18	0·65	0·038	0·036	0·10	0·04	0·05

W	V	Ti	Co	Cu	Al	Pb	Sn
0·02	0·03	0·02	0·02	0·11	0·015	0·05	0·01

Specimens large enough for the subsequent tensile test were required; 5-in. lengths of these bars were therefore austenitized in air for 2–4 h at 800° C and transformed in a lead bath at a high sub-critical temperature to obtain a coarse pearlite. The particular specimen on which almost all the present results were obtained had already undergone heat-treatment once before the final transformation. It was re-annealed for 2 h and quenched at 715° ± 10° C for 2 h. Owing to an experimental mishap, the bar was allowed to remain in the bath during cooling of the furnace for 5 h, and had then to be re-heated from room temperature to about 300° C in 1–1½ h to melt the lead and remove the bar. The steel had therefore undergone an ageing treatment at a series of temperatures, after transformation.

A 2-in. gauge length was then machined from two sides of the bar for the tensile test, and a third surface prepared for etching by mechanical polishing, followed by an electrolytic finish in the chromic–acetic acid mixture recommended by Morris.[10]

Nital or picral were at first used as etching reagents, but it was found that the clarity of microstructures so developed varied over the surface, as if partially obscured by a film. This effect has also been noted by Heidenreich, Sturkey, and Woods,[11] who claim that a mixture of hydrochloric acid and ferric chloride gave better results; this was also tried, but without marked improvement. A much more convenient procedure is electrolytic etching in a 10% aqueous solution of chromic acid.[12] This is sensitive and easily controlled, being less rapid than chemical etches, and does not stain the metal, so that no elaborate rinses are needed to produce a clean surface. It has been used throughout this investigation.

Optical Microscopy

The specimens were examined with a Vickers projection microscope. It is often advantageous, at the highest magnification, to supplement normal observation with the following methods:

(i) Varying the focus on a specimen illuminated by a narrow beam

(ii) Use of the oblique illumination obtained by the aid of the metal tongue illuminator provided in the instrument as an alternative to the half-silvered plate for normal incident light. Such techniques, as has been pointed out by Zernike,[13] are capable not only of increasing contrast but also of revealing the existence

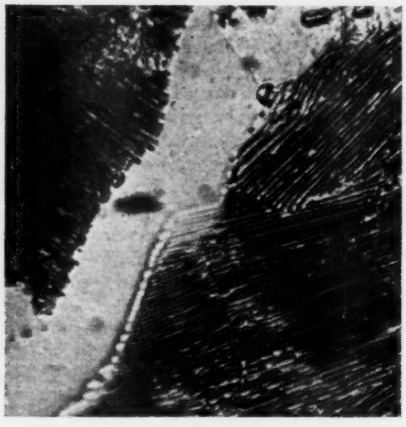

Fig. 3.—Free ferrite area containing 'ghost' patterns related to adjoining pearlite. Optical photograph in normal incident illumination × 1700

of fine structure below the optical resolution limit, though they entail some sacrifice of conventional resolving power. Dark-ground illumination and phase-contrast microscopy have also been used in this work, but have not revealed detail undetected by the above methods.

Electron Microscopy

Replicas of the surface were made by a two-stage process, using Perspex as the intermediate plastic negative and evaporated carbon as the final film. The techniques will be described in detail in Part II. The replicas were viewed, unshadowed, in a Philips 'Metalix' electron microscope. It was occasionally found desirable, even when not taking stereoscopic photographs, to tilt the specimen through angles up to 30° to increase contrast.

RESULTS

The electrolytic polish revealed the presence of rows of inclusions, aligned by rolling, shown in Fig. 1. The size and distribution of these particles suggests that they are sulphides, oxides, or silicates; the analysis (showing low-sulphur content, a perceptible amount of silicon, and an undetermined oxygen concentration) that the two last-named may predominate. However, they have not yet been definitely identified.

Examination of the etched surface showed that some decarburization had occurred during austenitizing, leaving areas of free ferrite delineating the austenite boundaries. Under suitable illumination these patches had a mottled texture (Fig. 2), while in places there appeared patterns related to the orientation of adjacent pearlite colonies (Fig. 3), phenomena which indicate the existence in the ferrite of a fine

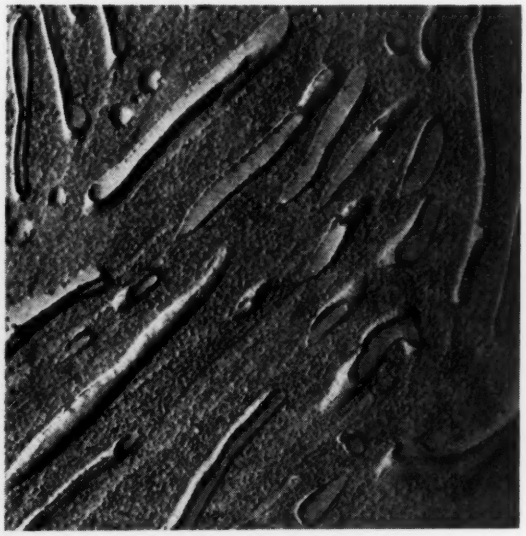

Fig. 4—Pearlite, electrolytically etched in chromic acid, showing variation of fine precipitate in ferrite round cementite particles, and rimmed appearance of cementite. Electron micrograph of Perspex-carbon replica × 15,000

Fig. 5—(*a*) Difference in precipitate size in free and pearlitic ferrite; (*b*) discontinuity in cementite lamellæ. Electron micrograph (Black patches are specks of dust on the replica) × 7500

precipitate whose distribution is affected by the presence of cementite. Electron microscopy confirmed that this precipitation is general throughout the pearlite as well as in the free ferrite. Figure 4 shows a replica area demonstrating clearly a particle size and dispersion of about 100Å, with marked variation in the neighbourhood of cementite particles. In Fig. 5 the precipitate size in the pearlite region is similar to that of Fig. 4, but is much coarser in the free ferrite area on the right where particles 2000Å or more in diameter can be seen. The precipitate seems to be spheroidal, rather than in the form of rods or plates.

The specimen was kept at room temperature and repeatedly raised to a temperature of 120–140° C for 1 h or more at a time, to make the plastic pressings for electron microscopy. During six months the surface was several times repolished and etched, but no change in the precipitate was observed. At the end of this time the surface was machined away to a depth of $\frac{1}{16}$ in. and again examined. No trace of precipitate could then be detected, nor did it reappear during the subsequent replicating or storage at room temperature for a further three months.

That the precipitate is confined to the surface layers indicates that it was formed during the second heating of the specimen to 300° C rather than during furnace-cooling. A phase nucleated at an ageing temperature between 140° and 300° C, probably nearer to the latter, in the form of particles with dispersion of about 100Å and dimensions 100–1000Å, whose formation is affected by the neighbourhood of cementite, may be tentatively identified as either ϵ-iron carbide, which was detected by Tsou, Nutting, and Menter[14] after ageing α-iron supersaturated with carbon below 300° C, or as normal cementite, which was shown by the same workers to appear after ageing as a fine precipitate at 300° C or above. Direct comparison with this work is not possible, however, as particles smaller than 300–500Å were not reported, and when detected were in the form of plates. It is evident

Fig. 6—Stereoscopic pair (stereo angle 14°). Cementite lamellæ with etch-resistant rim exposed at point marked by arrow. Electron micrograph × 15,000

that further investigation of this subject is necessary.

Many of the cementite particles exhibit a rimmed appearance, as in Fig. 4, the rim sometimes being a continuous black outline or a granulated edge. This is illustrated by the stereoscopic pair in Fig. 6. Two cementite plates of rather irregular shape, oblique to the surface, join at its boundary two members of a colony (on the left of the area) of more regular lamellæ. There are three points of interest:

(i) The black outline on the cementite rim seems to be a heavy deposit of carbon, which has evidently migrated preferentially to the corresponding feature on the plastic negative. This appears to be a characteristic of the replica technique, and limits the resolving power at sharp edges.* Thus the true condition of the rim may be the discontinuous granulation seen in the preceding photograph

(ii) One side of the particles has a different texture from the other. In stereoscopic view, the rim seems to overhang a smooth white surface. Generally it seems to enclose an area without any apparent texture

(ii) At the point marked by an arrow, at which one of the irregular particles joins a lamella of the parallel colony, this rim is absent, showing the rim of the lamella in section; it can be seen to stand a considerable distance above the rest of the plate, a height which is estimated from parallax measurements at 500–1000Å.

It is clear that the cementite is attacked inhomogeneously by the electrolytic etch, a fact which no doubt reflects some kind of segregation within the carbide. This segregation might be of two types: a variation in carbon composition, in parts of the cementite, from the normal Fe_3C, or an inhomogeneity in alloy content. With regard to this it may be observed that, of the elements present in the steel in appreciable amounts, manganese and nickel are both known to be extensively soluble in cementite. Hultgren[15] found that pearlitic cementite in a steel containing 33% Mn had a high manganese content. No metallographic observations of this kind on low-alloy cementite are known to the writer. Again, further study is required to elucidate this phenomenon, though analysis of composition fluctuations on such a small scale is likely to be extremely difficult.

The following observations bear on growth structure of pearlite. With the end in view of determining the effect of deformation on the aggregate, attention was naturally directed to departures, in the undeformed metal, from the ideal structure of colonies of plane parallel lamellæ on which theories of pearlite precipitation are usually based. These deviations will be collectively termed ' growth faults.'

One example of the first of these faults to be considered may be seen in Fig. 5, in which a discontinuity in the cementite lamellæ traverses the colony. Such

Fig. 7—Discontinuity in cementite lamellæ. Electron micrograph × 7500

* Professor F. C. Frank has suggested that cracks which are filled with carbon during evaporation of the film are formed in the Perspex at such places.

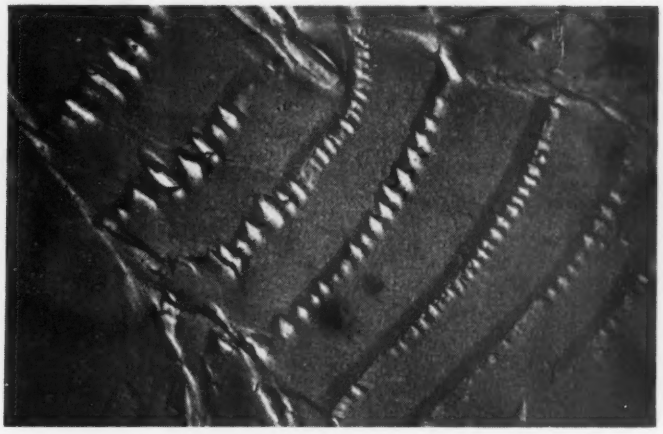

Fig. 8—Branching of cementite (Replica of deformed surface) × 10,000

line discontinuities are frequently observed; sometimes the two parts of the cementite lamellæ projecting above the surface are joined, sometimes apparently disconnected. A second example is shown in Fig. 7. A theory of formation of these displacements has been advanced in another publication, by Professor F. C. Frank and the present author,[17] in which it is suggested that they are the result of the healing-up of troughs in the surface of the growing colony. If the lamellæ are slightly out of register on either side of such a concavity this process can produce the appearance of discontinuity on an arbitrary cross-section. It is clear, too, that if the spacing of the growing colony is larger than the optimum value determined by diffusion and surface energy criteria,[3] further edgewise growth from these discontinuities will take place to give an interleaved structure of smaller spacing. This is one way in which branched crystallization as described by Smith,[5] could originate.

It is likely that branching of single lamellæ unaccompanied by multiplication of neighbouring sheets also occurs, but unambiguous evidence of it on a polished surface will be rare. By chance one photograph has been obtained (Fig. 8) which shows branching in a direction lying in the specimen surface. (This area was on a replica of a deformed specimen; diffuse slip lines can also be seen.)

Lamellæ frequently undergo sharp changes in orientation as well as curvature, often in a direction related to that of a neighbouring colony. One example of this type of fault is apparent in the optical photograph (Fig. 2), in the colony to the left of the free ferrite area. Figure 9 is an electron micrograph of such a tendency. One possible cause of it is growth of the colony through the carbon concentration gradients round the edge of a neighbouring colony, which in the case of Fig. 9 probably lay just above the surface before polishing. A second possibility has been suggested[17]: that the ferrite–cementite surface energy is highly anisotropic, so that specific orientations are preferred; if for any reason a sheet departs from one of these orientations, it will seek another for which the surface energy is a minimum. Curved pearlite lamellæ are frequently striated and tend to produce

Fig. 9—Deviation of lamellar orientation of cementite (slightly out of focus) × 11,250

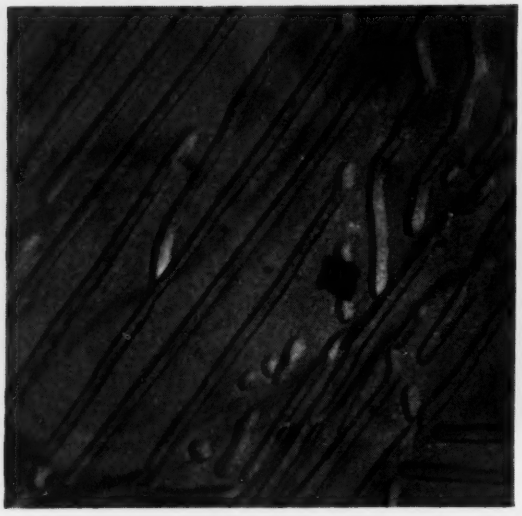

Fig. 10—Onset of rod-like growth in pearlite colony × **5000**

rod-like shoots from their edges, which is shown in the above paper to support this view.

Whatever its origin, growth of cementite in the form of laths or rods is fairly common in pearlite. Smith and Nutting[7] observed that cementite plates extracted from pearlite often have rod-like projections growing from their edges. There is evidence that inhomogeneous carbon distribution may sometimes be responsible for this; Fig. 10 shows a striking example of a whole colony apparently succumbing simultaneously to some influence, which may well be that of a neighbouring colony, tending to growth of rods. (This photograph, like Fig. 8, is of a deformed specimen).

Finally, the effect on cementite morphology of inclusions must be considered. Inspection of an area containing the stringers of these particles shows that they are intimately enclosed by a sheath of cementite, shown in Fig. 11. Often, as in the right-hand inclusion, a plate of cementite grows round a particle and resumes its lamellar form on the other side. The etch-resistant rim of the carbide is nearly always clearly visible round the inclusion edge. Inclusions do not appear to have any long-range effect on the carbon distribution as Mehl suggested, the geometrical form imposed by the growth of cementite described above does seem, however, to be responsible for certain re-entrants occasionally visible in cementite lamellæ (Fig. 12).

CONCLUSIONS

(1) A precipitate is formed in ferrite on ageing isothermally transformed pearlite at a temperature between 140° and 300° C. This may be ϵ-carbide or cementite.

(2) Some inhomogeneity in pearlitic cementite has been detected, which is thought to be due to alloy segregation, possibly that of manganese.

(3) The following types of growth fault have been distinguished:

Fig. 11—Growth of cementite round inclusions × **15,000**

(i) Linear discontinuities in cementite lamellæ
(ii) Branched crystallization
(iii) Deviations of lamellar orientation caused by the perturbing effect of neighbouring colonies, or by anisotropy of ferrite–cementite surface energy
(iv) Rod-like growth, arising possibly from the same causes as (iii)
(v) Growth of cementite round inclusions.

Acknowledgments

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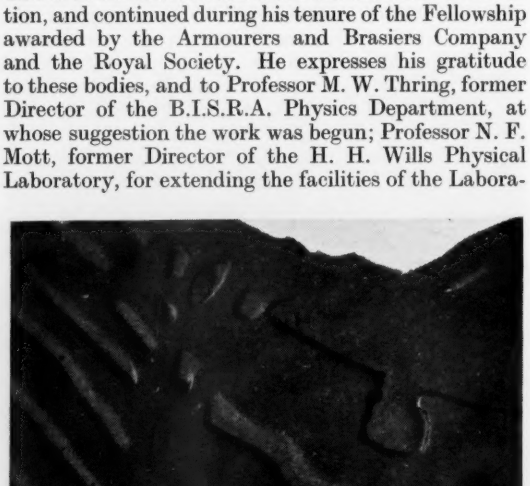

Fig. 12—Re-entrant produced by growth of cementite round inclusions × **15,000**

tory and for his interest and encouragement, and Dr. H. F. Kay and his assistants for their cooperation and advice on the use of the electron microscope. Above all, he acknowledges the help afforded by many discussions with Professor F. C. Frank.

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Part II—DEFORMATION AND FRACTURE

Introduction

THIS PAPER reports the results of an investigation of the nature of plastic flow in pearlitic steel. In Part I,[1] some features have been described of the microstructure of pearlite observed, before deformation, on the specimen on which most of this work was done.

Previous work on the deformation of pearlite has been mainly confined to the correlation of the results of mechanical tests with the dispersion, variously defined and measured, of the cementite. The most comprehensive study of this kind is that of Gensamer *et al.*,[2] who determined the tensile properties of a number of isothermally transformed eutectoid steels as a function of the 'mean ferrite path,' a parameter which represented the mean uninterrupted path through the ferrite for an idealized structure of colonies of perfectly plane parallel plates, randomly oriented. These workers state that the logarithm of the yield strength is a linear function of the ferrite path. There is considerable scatter in their results, which are insufficient for any one material to justify great confidence in a particular relationship; nevertheless the data demonstrate a marked influence of microstructure on mechanical properties. Jenkins, Mellor, and Jenkinson[3] made microscopic observation of a number of carbon steels after both creep and short-time tensile tests over a wide temperature range, and reported that the mode of deformation in an eutectoid steel up to 450–550° C appeared to proceed by shear on a plane situated at an angle to the lamellæ. Only slight movement appeared to take place in a direction parallel to the lamellæ.

Optical metallography of eutectoid steel is limited in scope because the greatest dispersion of the carbide is only just above the resolution limit. In the present research both optical and electron microscopy have been used.

SYNOPSIS

The results of a study of plastic deformation and fracture of pearlitic steel by optical and electron microscopy are reported. Techniques developed for the purpose include (i) a two-stage replica process for electron microscopy, using Perspex as the intermediate material and evaporated carbon as the final film, suitable for reproducing rough surfaces, including fracture surfaces, and (ii) photogrammetry of stereoscopic pairs.

Deformation in pearlite proceeds by fine slip in ferrite parallel to the lamellæ where the resolved shear stress is great enough, or by slip transverse to the lamellæ in unfavourably oriented colonies. In the latter case the ferrite slip is accommodated by plastic deformation of cementite and ferrite/cementite interfacial slip. Fine slip in ferrite tends to aggregate at faults in the lamellar pattern and the ends of cementite plates; in the early stages of deformation it sometimes undergoes sharp changes of direction between lamellæ, giving a surface pattern of arrowhead-shaped slip lines.

Fracture surfaces exhibit lamellar patterns which may be identified with the intersection of pearlite colonies with a surface of brittle fracture, following paths determined by previous slip. Some fine steps, of height 100Å (in order of magnitude), have also been observed on replicas of such surfaces, but are at the moment unexplained.

1191

EXPERIMENTAL PROCEDURE

The composition, heat-treatment, and surface preparation of the tensile specimen used in these experiments have been described in Part I, but will be summarized here for convenience. A bar of plain carbon eutectoid steel 5 in. × ½ in. × ½ in. was austenitized at 800° C, transformed in a lead bath at about 715° C, and machined to a shape suitable for tensile deformation. It was then electrolytically polished, and electrolytically etched in chromic acid. Optical examination revealed that some surface decarburization occurred during austenitizing in air, leaving patches of free ferrite delineating the austenite boundaries.

Optical Microscopy

Spacing Measurements

It was thought desirable to make an estimate of the interlamellar spacing, as the mechanism of deformation may depend on this, and Pearsall's limit method[2] was adapted for the purposes. This idealizes the pearlite structure as an aggregate of colonies of plane parallel plates with a constant spacing, but it has been shown to give values close to the mean spacing derived from more sophisticated techniques.[4]

Essentially, the method consists of a measurement

of the area fraction of pearlite intercepting a surface unresolved by a microscope objective whose resolving power is known (it is usually assumed to have the theoretical value). This is the area occupied by pearlite with an apparent spacing (on the plane of polish) up to the limit of resolution. The theoretical value of this area is

$$f_s = \cos\left(\operatorname{cosec}^{-1}\frac{s}{s_0}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where s_0 is the true spacing, which may thus be estimated. Two objectives were used for this measurement: one of 8 mm focal length and N.A. 0·45, and one of 4 mm focal length N.A. 0·65. Observation was made with a Vickers projection microscope, which was used throughout this work.

The area of unresolved pearlite was estimated by lineal analysis with a micrometer eyepiece. This is quicker than direct measurement on photographs, though tiring. The following results, corrected for the free ferrite present, were obtained in six determinations:

Objective	f.l. 1·8 mm; N.A. 0·45			f.l. 4 mm; N.A. 0·65		
—Mean spacing $\times 10^{-5}$ cm	3·8	4·8	5·5	4·0	3·7	3·3

A considerable variation of true spacing over a specimen as large as is used here would not be surprising; however, the method does not entirely preclude a bias dependent on the resolving power of the objective.

An independent measure of spacing was obtained by electron microscopy, this time by outlining on tracing paper the areas of micrographs with apparent spacing below a certain arbitrary value. This was taken as 1 mm on prints at a magnification of ×2250; 11 areas, 8½ in. × 6½ in., were thus measured, and the tracings then cut up and the relative areas weighed.[4] The value derived from this determination was $4{\cdot}4 \times 10^{-5}$ cm; the mean of all measurements was $4{\cdot}3 \times 10^{-5}$ cm.

Surface Profile Microscope

To survey rough deformed surfaces, Tolansky's light profile was used.[5] This device was calibrated with sufficient accuracy for the purpose of this work as follows. A surface step which showed a suitably sharp displacement of the reference line was observed; first with the profile which employs oblique, narrow-beam illumination, and then with normal illumination and a full condenser aperture. The depth of focus in the latter case is so much reduced, relative to the conditions of the profile microscope, that the height of the step can be measured by the microscope's fine focus control, which is graduated in microns. The sensitivity of the profile with a 1·8-mm objective on the particular model at Bristol is thus estimated at about × 1·8 the lateral magnification.

Electron Microscopy

Replica Technique

The first requirement for electron microscopy was a replica technique applicable to rough surfaces. Dry-stripped Formvar and methyl methacrylate, polymerized on the surface,[6] were tried but difficulty in stripping from the deformed metal was experienced in both cases. Perspex has proved more suitable. It has been used for replicas in optical interferometry, and has been shown to give reproduction of vertical detail to better than 100Å.[7] Its use in electron microscopy has not been previously reported, but is most convenient for the present problem.

Under pressure of a few lb/in², $\frac{1}{16}$-in. Perspex sheet was clamped on to the metal surface and heated to 120–140° C for about 30 min. During cooling it undergoes a slight contraction, about 0·5% according to Tolansky. This is sufficient to prevent the plastic being keyed to the surface when cold, though not enough to affect faithful replication of detail.

The disadvantages of this technique are the temperature and pressure involved, which make it unsuitable for soft metals or those which undergo phase changes at about 100° C. In the present case no visible change in the microstructure was observed during repeated replication, though ageing effects in pearlite at a higher temperature have been reported.[1]

The final replica was next evaporated on to the negative pressing of the steel surface. Film silica shadowed with gold–palladium alloy was at first used for this film, but the self-structure of the shadow obscured fine detail which was clearly resolved by carbon replicas.[8] Accordingly these were used, unshadowed, in all the work reported here.

The plastic replica was then dissolved away by a procedure similar to that of Appelbe.[9] The composite replica was fixed to a strip of brown gummed paper, with a mesh grid protected by a piece of plain paper between the replica surface and the gum. The whole was then immersed in chloroform (in which the adhesive is not soluble), which dissolved away the Perspex, leaving the carbon film on the grid, ready for examination. It was found that the carbon, though stable in the electron beam, tended to break up during dissolution of the plastic, possibly as a result of the strains imposed by expansion of the Perspex in this process. The film was strengthened by a backing of nitrocellulose, which was subsequently removed by washing in baths of amyl acetate. Care was necessary with this washing, since if incomplete, it sometimes left artefacts on the replica surface.

This replicating procedure has also proved suitable for the very rough surfaces produced by fracture. In this case thicker sheet (¼ in.), a higher temperature (about 150–160° C), and greater pressure are desirable. It is also necessary to prevent lateral flow of the Perspex, which will otherwise be extruded sideways under pressure, instead of allowing penetration of the fracture surface. This is accomplished by supporting the plastic on the other side by a rough surface and by clamping it inside a ring guard. Carbon films on such surfaces seem to be stronger, and do not usually need backing during immersion in chloroform.

The replicas so produced vary in quality, but their best resolution is less than 100Å, and is possibly better than the resolution of the Bristol microscope (approximately 50Å).

Stereophotography

It is obviously desirable to contour deformation and fracture surfaces. In viewing the unshadowed carbon replicas used in this research, stereoscopic techniques[10, 11] have been extensively employed. The Philips electron microscope used is well adapted for

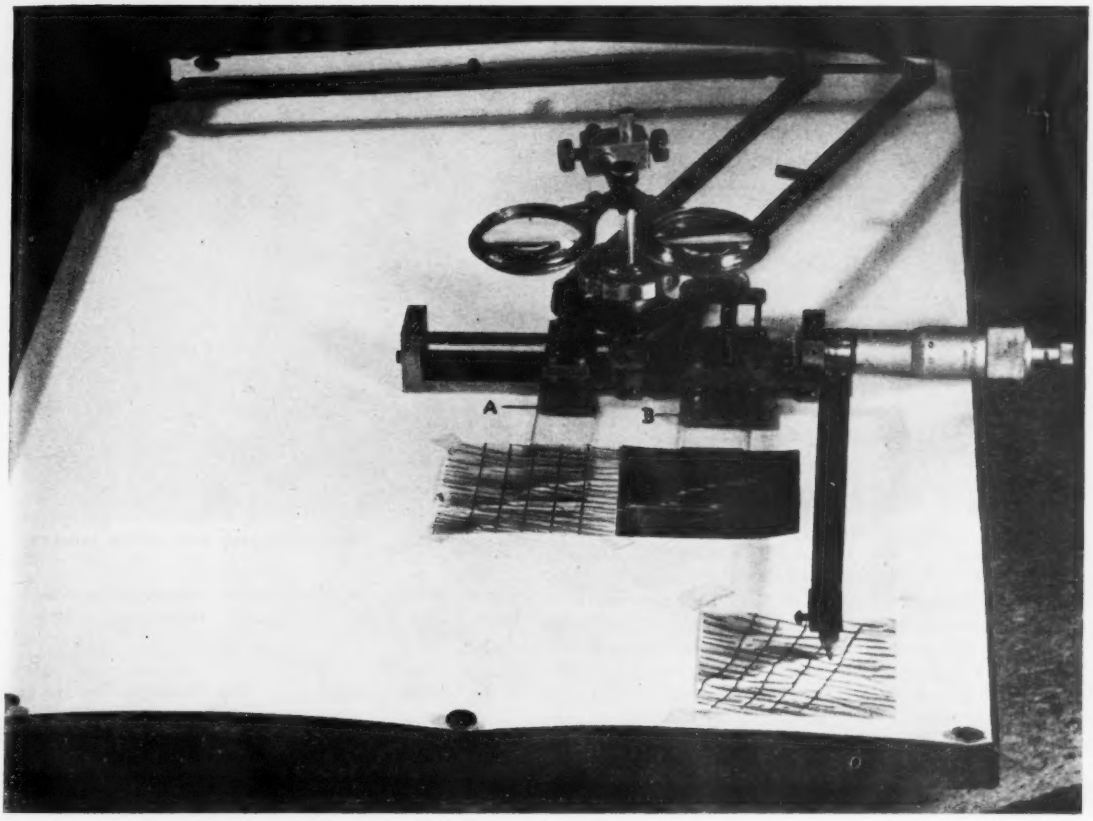

Fig. 1—Stereomicrometer for parallax measurement on electron micrographs.

this purpose, since specimen tilt either side of the normal position up to 14° is possible, and on one side up to about 50°. For convenient and accurate measurement of tilt, a graduated head, visible to the operator along the top of the microscope column, was fixed to the specimen holder. To calibrate the image rotation produced by the electromagnetic lenses, one side of the slot in a silver grid (of the type normally used in the Philips microscope) was photographed at a series of magnifications.

As no instrument suitable for mapping small prints was available, the stereomicrometer illustrated in Fig. 1 was constructed. Two sheets of glass which carry the wandering dots for parallax measurement, are attached to the carriages A, B on the body of the instrument. The left carriage may be locked in a suitable position, while the right, spring-loaded and moved by a micrometer head, measures parallax differences over the surface of the print.* The prints are viewed through two lenses at the focal distance, and the whole device is clamped to a chart-table plotting arm to maintain its orientation constant to the base line of the stereoscopic pair.

The stereomicrometer may be used in either of two ways:

(i) To plot conventional contours. This is accomplished by fixing a pencil to the body of the instrument, and tracing out lines of constant parallax over the plane of the print. Suitable photographs should have plenty of surface detail, without too much contrast

(ii) To plot surface profiles along a given line. Instead of presenting these separately, it is sometimes convenient to trace them out directly on a photograph, in order to relate them to surface detail. The procedure for this is as follows:

The reference line is drawn on the left-hand print, preferably perpendicular to the base line, since the sensitivity of a profile drawn in this way is then greatest. A pencil is attached to the right-hand carriage, and beneath it is oriented a duplicate of the right-hand print, to which it is parallel. The plotter is then moved along the reference line and the parallax marked at intervals, giving a trace analogous to that of the light profile microscope. With the stereo angle of 14° usually employed, the difference is that the sensitivity is roughly half that of the lateral magnification.

The equation for conversion of parallax differences to relative elevations in the form suitable for this work[11] is:

$$x = \frac{y}{2M \sin\sigma} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

* A description of the operation of this class of instrument may be found in most books on aerial surveying (e.g. reference 12).

It should be noted that maps made by this means are in perspective rather than orthogonal projection; i.e. changes in the horizontal scale are ignored. The distinction is unimportant in electron microscopy.

Fig. 2—Shear of free ferrite × **1700**

where x is elevation, y parallax, M magnification, and σ the angle of specimen tilt about the normal.

It is sometimes useful to estimate the height of features vertical to the surface plane, as shown from their appearance in a single oblique photograph (cf. aerial surveying[13]). This is equivalent to measuring the parallax on a stereoscopic pair of which one member is taken to the surface. If ϕ is the angle of tilt,

$$x = \frac{y}{M \sin\phi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Deformation

The rectangular specimen 2 in. long, machined from two sides, was pulled to fracture in a tensile testing machine. Unfortunately the specimen broke before the final load could be recorded; the elongation was only 2·5%, a figure which suggests that the wedge grips used in this test did not allow uniaxial loading.

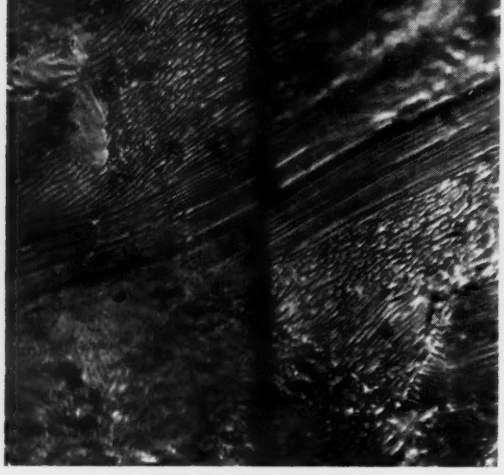

Fig. 3—Shear parallel to lamellæ × **1700**

Fig. 4—Shear steps transverse to pearlite lamellæ × **1700**

Slight necking, indicated by a reduction in area of 3·5%, occurred in the region of fracture.

RESULTS

Optical Survey

Optical examination of surface profiles on the deformed surface yielded the following points of interest:

(i) Large shear deformation of free ferrite areas (Fig. 2)

(ii) Shear movement in many colonies parallel to the lamellæ. Sometimes this is apparently homogeneous on the same scale, sometimes localized to fairly sharp steps, as in Fig. 3. This observation is contrary to the conclusion of Jenkins, Mellor, and Jenkinson[3] mentioned in the Introduction, but would be difficult to make without the light profile

(iii) Shear steps transverse to the lamellæ, as described by Jenkins *et al.* These vary in height over a very wide range, from the limit of resolution to several microns: Fig. 4 is an example

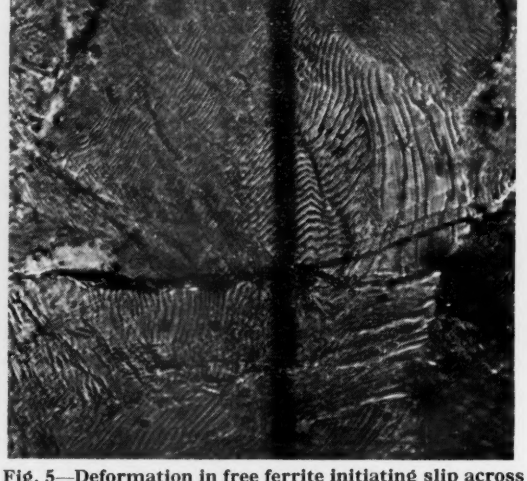

Fig. 5—Deformation in free ferrite initiating slip across pearlite colony × **718**

(iv) The shear movements in (i) and (ii) can sometimes be seen to give rise to the transverse slip of (iii). Figure 5 shows shear of a free ferrite area, apparently with a direction which has a component lying in the surface, initiating slip across a colony (to the right of the reference line) where displacement of the cementite lamellæ can be clearly resolved,

(v) The transverse slip eventually develops into cracks. This may be deduced from areas such as that shown in Fig. 6, where a crack is parallel to slip of this nature, and from the fact that fracture always appears to run across colonies rather than parallel to the lamellæ. This observation was also made by Jenkins *et al.*

Electron Microscopy

Special interest attaches to the shear across pearlite colonies illustrated by Fig. 4, since it requires accommodation by the cementite, and among several possibilities there is no obvious way in which carbide lamellæ of such dimensions might behave under the shear stress concentrations induced by deformation of the ferrite. Particular attention was paid to this question in scrutinizing replicas of deformed surfaces.

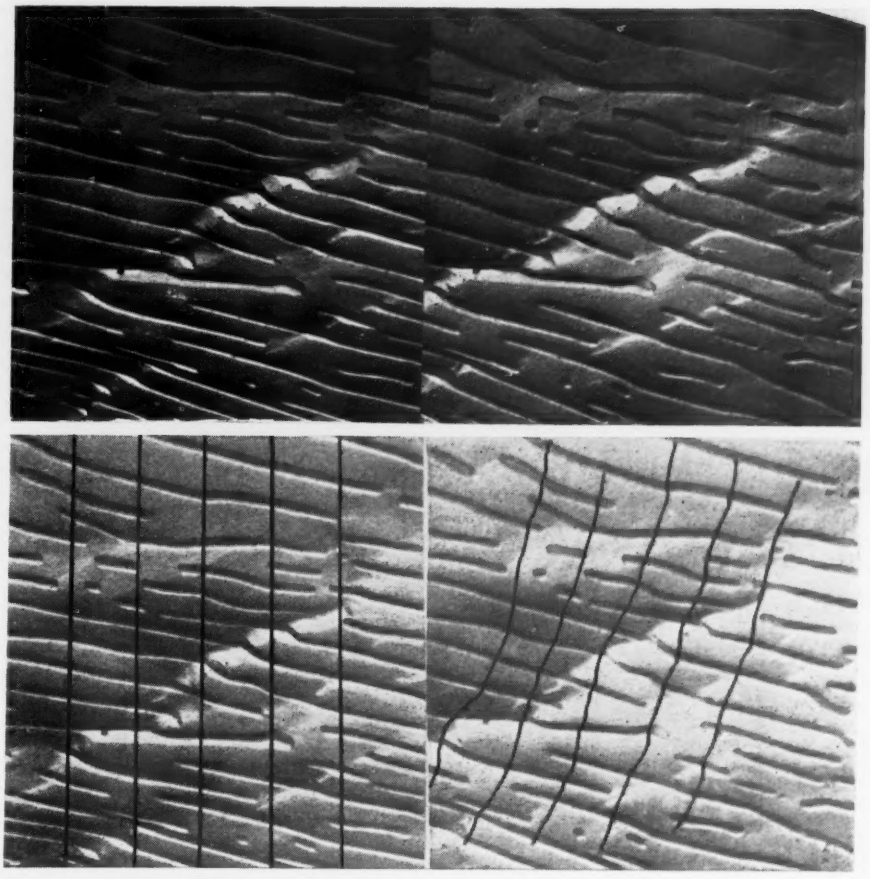

Fig. 7—Stereoscopic pair showing slip transverse to lamellæ accompanied by deformation of cementite and ferrite/cementite interfacial slip. Stereo angle 14° × 10,000

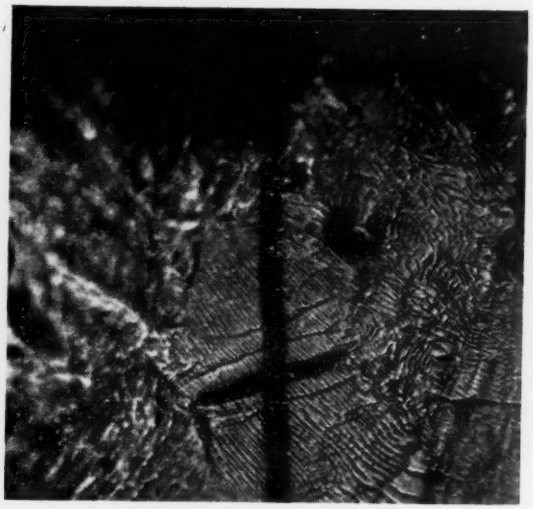

Fig. 6—Crack across pearlite colony × 718

Figs. 2–6 are optical photographs with light profile microscope, (Figs. 7–13 and 15–18 are electron micrographs).

The significance of the two stereoscopic pairs (Figs. 7 and 8) derives from the fact that the replica surface is tilted through a considerable angle, as shown by profiles mapped on the duplicate photographs, allowing a clear view of several typical features of pearlite deformation.* The parallax measurements afford an estimate of the height of the slip steps visible in these two pairs; e.g. in Fig. 7, the main shear appears to be about $0{\cdot}2\mu$. The tilt of the surface affords an independent calculation, if it is assumed that the lamellæ in the centre of the field are nearly normal to the surface. The profile shows that the surface makes an angle of about 36° with the picture plane, while apparent relative displacement across the step of the two parts of a lamella is $0{\cdot}1\mu$; therefore

* In all topographical studies of replicas it must be remembered that the replica usually tears at some point. Surface deformation which is not obviously related to microstructure must be regarded with reserve.

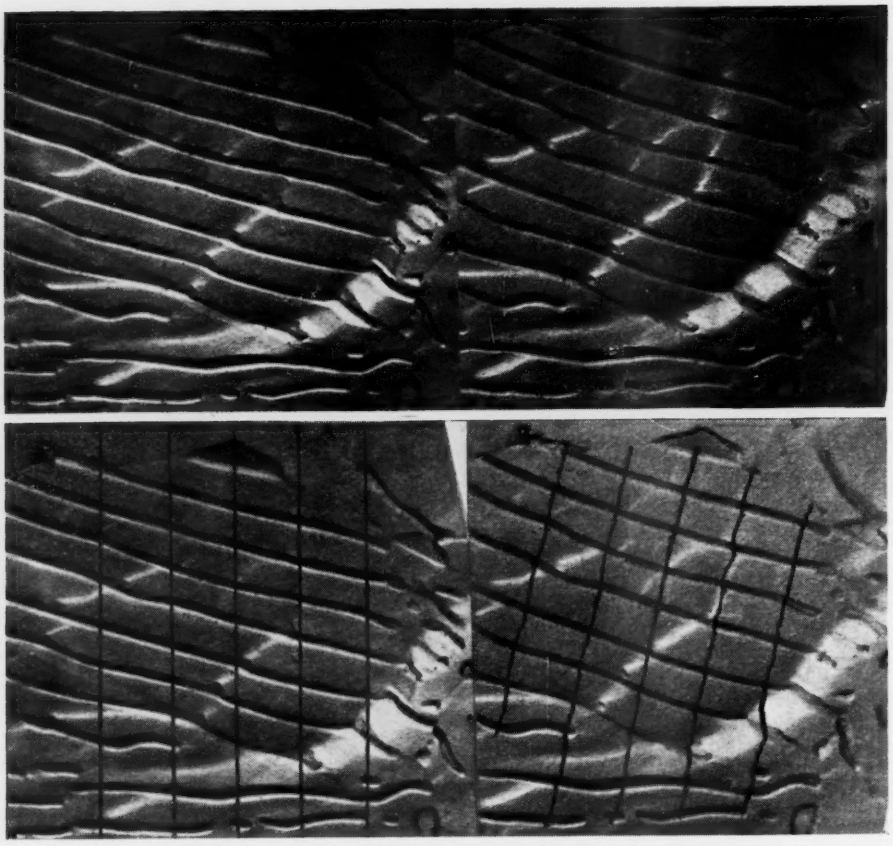

Fig. 8—Stereoscopic pair. Slip in ferrite accompanied by deformation of cementite and interfacial slip. 'Arrowhead' slip can also be seen in the ferrite. Stereo angle 14°. × 10,000
(In Figs. 7 and 8 the profiles mapped on duplicate pairs show surface tilt; the vertical scale is approximately half the lateral magnification).

the application of (3) estimates the height of the step at $0{\cdot}21\mu$.

The cementite undergoes perceptible plastic deformation by slip, in a direction which has a considerable component lying in the plane of the lamellæ. Pearlitic cementite in fact appears to be able to accommodate shear displacements of up to 1μ or more without fracture, though it is evidently possible for an independent crack to develop at steps much smaller than that, as Fig. 6 shows.

Fig. 9—Slip lines in free ferrite associated with neighbouring cementite lamellæ × 7500

The slip has exposed part of the surface of the cementite plates (Fig. 7), and shows that even at room temperature a limited amount of interfacial slip can occur between the ferrite and cementite phases. Such relative movement might nucleate slip at sharp projections of cementite in the ferrite, as suggested by Fig. 9, in which the slip lines in an area of free ferrite seem each to be associated with a lamella of the adjacent colony.

The rounded contour and diffuse character of the ferrite slip (as in the bottom left-hand corner of Fig. 8), indicates that the 'steps' are aggregates of the fine slip lines evident everywhere in the deformed regions down to the limit of visibility. Resolution of these aggregates into their component fine slip is apparent in Fig. 10. The similar appearance of the slip in the free ferrite also prompts the suggestion that the wavy slip lines in body-centred cubic metals are always of

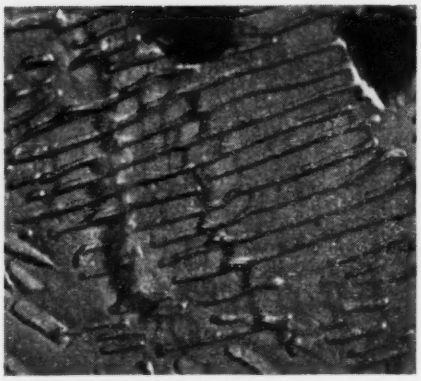

Fig. 10—Aggregates of fine slip lines in pearlitic ferrite (Black patches are dust on the replica) × 11,250

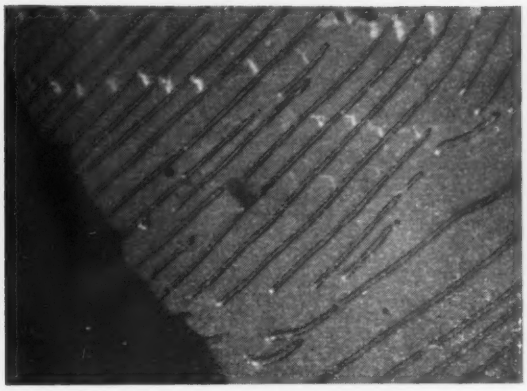

Fig. 11—'Arrowhead' slip in pearlitic ferrite × 7500

this nature. Care is necessary in interpreting these surface observations, for slip lines differ in character[14] on electropolished and mechanically polished surfaces of pure iron, and it has been suggested that those on electropolished surfaces may not be characteristic of the interior.[15] The cementite lamellæ generally follow the contour of the ferrite slip, and presumably also deform by fine slip. It will be seen in Fig. 7, however, that the cementite slip is not always in the same place as the ferrite step; the interfacial ferrite/cementite shear allows it to occur at a different point, presumably one in some way more favourable. One of the cementite lamellæ exhibits a step considerably sharper than that in the ferrite.

Figures 7 and 8 show a common modification of slip, making an angle with the lamellæ in the form of slip lines which undergo a sharp change of direction between cementite plates. This 'arrowhead slip' occurs even in the finest lines, as in Fig. 11. The very faint slip visible is probably not more than 100Å, since slip of this magnitude, known from parallax measurements on other areas, is quite clearly resolved, and may be a good deal less than that value. In Fig. 12 several of the arrowheads have one segment straight and sharp, but after change of direction they show a diffuse appearance. This phenomenon recalls the cross-slip exhibited by face-centred cubic metals under certain conditions.[16] It is yet uncertain, in the present case, whether this is of crystallographic origin, but it may be noted that the appearance of slip traces in α-iron crystals varies markedly with the surface orientation,[17] and it has been suggested that the wavy slip lines in body-centred cubic metals represent slip on a corrugated plane composed of elements of (110) planes.[18]

It is worth noting also that slip nucleated in this way tends to broaden out with increasing shear, which results in a curved slip surface. This process is beginning at one of the markings in Fig. 12.

Slip lines may often be seen to follow one or other of the growth faults in cementite described in Part I. It is not always easy to distinguish the distortion due to these faults from that produced by deformation, but Fig. 13 shows an unambiguous example of slip traversing a series of re-entrants in the lamellæ. This type of fault was recognized in Part I to result from growth round inclusions, which in this case lay mainly just above the present surface before polishing,

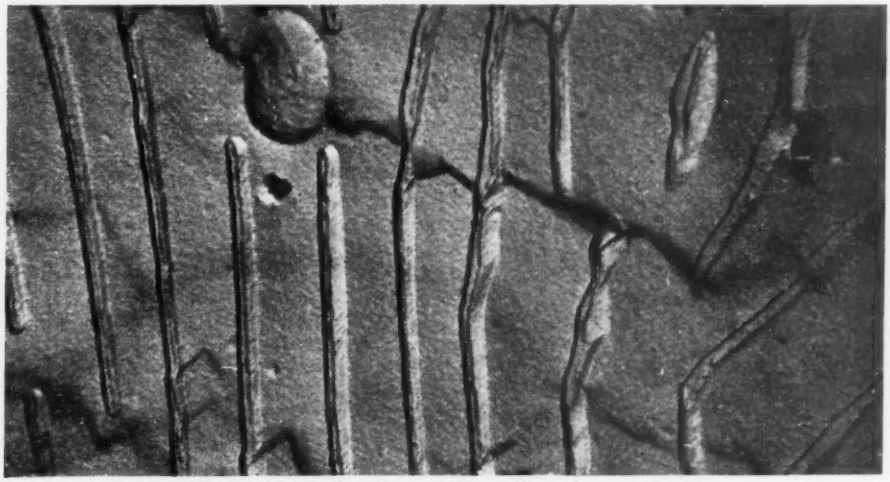

Fig. 12—'Arrowhead' and diffuse fine slip × 20,000

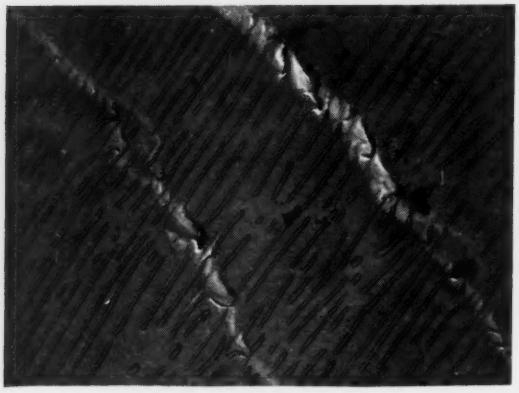

Fig. 13—Slip following growth fault in cementite lamellæ × 7500

though one is actually visible. This particular slip path must be a surface feature, but other evidence points to the natural conclusion that all the departures from lamellar growth enumerated in Part I offer preferred trajectories for slip, in some cases because the ferrite is continuous through them, in others because sharp projections of cementite concentrate stress.

Fracture

Owing to the small objective aperture the great depth of focus of the electron microscope, compared with that of the optical microscope, makes possible the examination of very rough surfaces. There is the drawback that replicas of the surface must be made, and there is no comparison with direct observation. The results of electron microscopy in this field must therefore be interpreted with caution.

The fracture surface which has been most studied was not that of the specimen whose deformation has been described in the previous section, but of another specimen transformed at approximately 710° C. The fracture surfaces of the coarse pearlite studied have the characteristics of brittle cleavage of ferrous materials described by Orowan.[19] There is a small patch of fibrous appearance at the origin of fracture, while most of the area has a coarser, brighter texture (Fig. 14). It is perhaps misleading in the present case to describe the fracture as crystalline, but there seems little doubt that its nature is directly determined by the microstructure.

Examination of fracture replicas strengthens this conclusion. There are on these many areas of a lamellar pattern, whose size and spacing correspond with those of pearlite colonies and may reasonably be identified with fracture across colonies, following the line of previously established slip pattern. Frequently these areas have the characteristics illustrated by the stereoscopic pair in Fig. 15. This has been mapped by conventional contours, on to a duplicate of the left-hand member, and lightly printed to contrast the lines.

It will be noticed that the lamellar surface slopes upward at an angle of about 40° to the foot of a cliff 0·5–1·0μ high, which bounds a relatively flat plateau. Evident on this plateau are a number of steps of height 100Å in order of magnitude, and two curious structures at the edge of the cliff, approximately 0·5μ above the level of the plateau, which are terraced by a number of these fine steps. Figure 16 shows these structures printed at a higher magnification, on paper of a more contrasting type. (The photograph is at normal incidence). The interlamellar spacing to the left of the pictures is about 0·2–0·5μ, allowing for the slope. The lamellæ on the fracture surfaces often have a rounded contour. It was thought at first that this was due to incomplete replication, but the appearance of the steps generated by slip across colonies at which fracture occurs (as revealed by surface studies) suggests that this characteristic of fracture replicas may be genuine.

Figure 17 shows a region (photographed at normal incidence) which is probably similar in character to Fig. 15, though it has not been mapped. Fine structure can be discerned on the plateau in the upper half of the picture.

In the examination of the deformed surface of the specimen discussed in the last section, one replica was obtained of the fracture area. Although of poor quality (due either to overheating or to contamination of some kind) this displays features which suggest that electron microscopy may yield valuable information concerning the onset of fracture, as well as on the process of cleavage. Figure 18 is a stereoscopic pair of this replica and, despite the stain and the fact that it has obviously not reproduced properly the etched pearlite, it shows lamellæ running up to the fracture surface on which a series of plate-like structures stand out in relief. These may well be the edges of cementite sheets exposed by fracture.

DISCUSSION

The metallography of deformed pearlite indicates the following sequence of events in plastic flow. Favourably oriented colonies yield by slip parallel to the lamellæ. In colonies whose orientation does not permit this mode of deformation, fine slip begins in the ferrite, and under the stress concentration of neighbouring colonies, general yield occurs by aggregation of fine slip at growth faults to produce large shears, which may be accompanied by deformation of cementite and ferrite/cementite interfacial slip. Cracks are initiated at these sites, one of which grows to the critical value demanded by the Griffith–Orowan criterion[20] for rapid propagation, and general fracture ensues.

Two points are suggested by this. First, the onset of yield bears a certain analogy to that in pure poly-

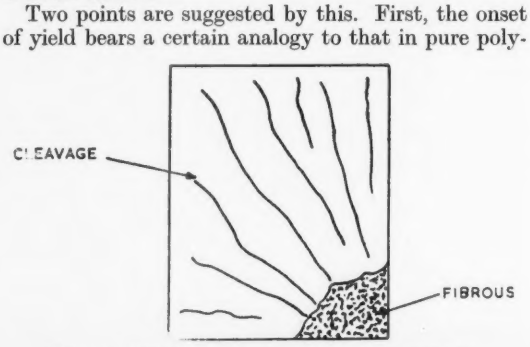

Fig. 14—Diagram of pearlite fracture surface.

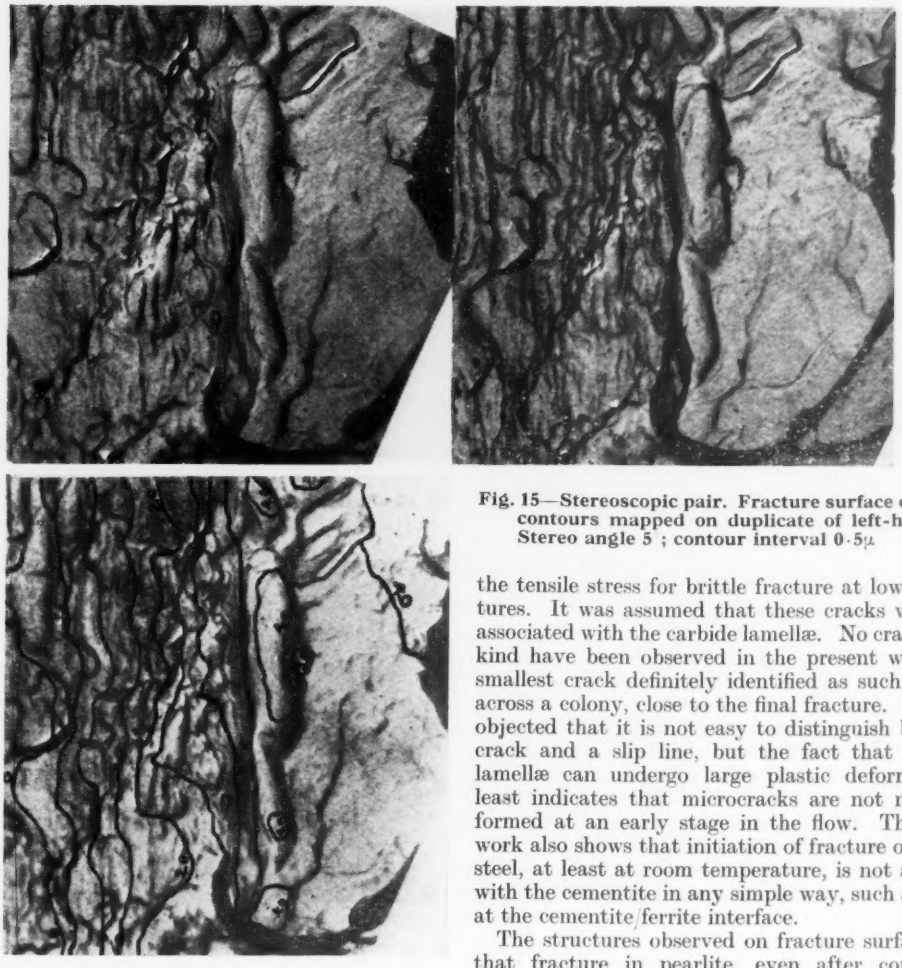

Fig. 15—Stereoscopic pair. Fracture surface of pearlite; contours mapped on duplicate of left-hand print. Stereo angle 5 ; contour interval 0·5μ × 10,000

crystalline metals, in which those grains in which the resolved shear stress on the slip system is highest yield first, and general yield occurs when the stress concentrations at the ends of slip lines are sufficiently high to induce slip in neighbouring grains. Therefore the yield point is a function of the length of slip lines, i.e. of the crystal size.[20] It may well be that the mechanical properties of pearlite are not solely dependent on the interlamellar spacing, but on the longitudinal dimension of the cementite. It has been shown in the course of this study that plastic flow can be nucleated at the ends of cementite plates. However, there is no evidence at present on the change of colony size with transformation temperature.

The other point on which this study provides information, though of a negative kind, concerns the ' microcrack ' theory invoked by Zener and Hollomon[21] to explain the observed increase of brittle fracture stress in steel with prior plastic deformation. It was suggested that the process of deformation involved the reorientation of a system of internal flaws, either pre-existing or produced by the first yield, which led to an increase, after deformation, of the tensile stress for brittle fracture at low temperatures. It was assumed that these cracks were to be associated with the carbide lamellæ. No cracks of this kind have been observed in the present work. The smallest crack definitely identified as such extended across a colony, close to the final fracture. It may be objected that it is not easy to distinguish between a crack and a slip line, but the fact that cementite lamellæ can undergo large plastic deformation at least indicates that microcracks are not necessarily formed at an early stage in the flow. The present work also shows that initiation of fracture of pearlitic steel, at least at room temperature, is not associated with the cementite in any simple way, such as parting at the cementite/ferrite interface.

The structures observed on fracture surfaces show that fracture in pearlite, even after considerable deformation, is of the same character as that generally designated ' brittle ' or ' cleavage.' The fine structure on fracture replicas still requires satisfactory interpretation, but it may be connected with fracture of either ferrite or of cementite. They may be associated with the dislocation pattern produced by slip.

CONCLUSIONS

The deformation process in pearlite has been investigated by surface studies with optical and electron microscopy. Deformation is accommodated by fine slip in ferrite parallel to the lamellæ where the resolved shear stress is sufficiently high, or by slip transverse to the cementite in unfavourably oriented colonies. In the latter case the shear is accompanied by plastic deformation of cementite and some ferrite/cementite interfacial slip. In such colonies the ferrite slip may also follow a zig-zag or ' arrowhead ' path in the early stages of deformation. Slip tends to aggregate at faults of various kinds in the lamellar pattern, and may be nucleated at the ends of cementite plates.

Examination of replicas of fracture surfaces have revealed patterns which may reasonably be explained by brittle fracture across pearlite colonies, following

Fig. 16—Fine structure on fracture surface of pearlite (detail of field of Fig. 15 photographed with normal incident beam) × 20,000

Fig. 17—Fracture surface of pearlite, showing fine structure × 15,000

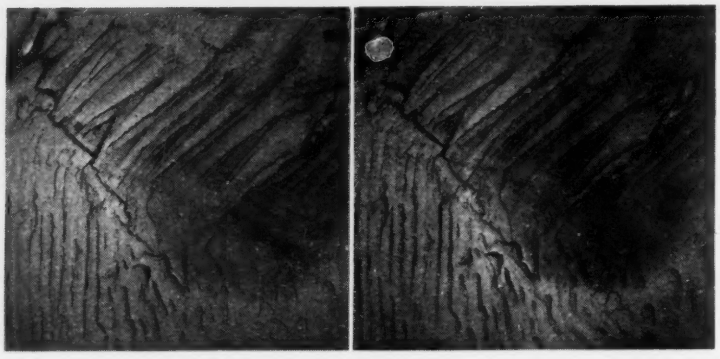

Fig. 18—Stereoscopic pair. Fracture area of pearlite surface, showing part of fracture surface. Stereo angle 5° (imperfect replica). × 5000

paths determined by previous slip. Fine structure on such surfaces is as yet unexplained.

Acknowledgments

The writer is indebted to the Royal Society and the Armourers' and Brasiers Company for a Fellowship to pursue this research.

In addition to the acknowledgments made in Part I, he wishes to thank Dr. J. M. Burch, who drew his attention to the work of Tolansky cited in the text, and Dr. B. Crossland and members of the Engineering Department, University of Bristol, for allowing him the use of one of their testing machines. He has continued to have the privilege of discussions with Professor F. C. Frank.

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By J. H. Chesters, C. Holden, and A. D. Robertson

Protection of Refractories by Moving Air Curtains

SYNOPSIS

Starting from the conception of a furnace in which the air enters at the opposite end to the fuel to form a sheet separating the flux-laden combustion gases from the refractories, the simpler idea of a moving air curtain directed from the backwall skewbacks over the underside of the roof has been developed.

Studies made both in the laboratory and on actual open-hearth furnaces show that what at first appeared to be a very simple idea is, in fact, quite complex, a moving air curtain entraining substantial quantities of furnace gases and being penetrated surprisingly easily by both coarse droplets and fine fume. Even so, numerous works tests suggest that relatively slow moving air curtains emerging from an essentially continuous slot afford sufficient protection to the refractories to warrant their trial in areas where excessive wear is normally experienced, e.g. in the region of an open-hearth furnace roof adjacent to the backwall. 1376

IT HAS LONG been known that iron-oxide attack is a major factor in the wear of open-hearth furnace roofs and that wear is particularly severe where the temperatures are high or reducing conditions are present. Quantitative information is now becoming available[1] on the amounts of iron oxide arriving at particular points on the roof during the progress of a heat. It has, for example, been shown that areas where wear is most rapid are in general areas of high deposition and, further, that the direction of arrival is in line with the suggestion that the iron oxide is picked up by flame gases at bath level and brought to the roof in a manner predictable from flow-pattern studies made in the laboratory and confirmed on actual furnaces.

The original concept of using a moving air curtain to protect refractories was extremely simple, but attempts to apply it in practice show that numerous complications arise, notably the tendency of moving streams of air to entrain adjacent gases and the ease with which both coarse and fine droplets penetrate a moving air curtain. The ideas patented in 1949 have still only found a limited application, but it is hoped that publication of the work done will stimulate others to carry out similar studies and thus increase the rate at which a more complete solution is obtained.

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Part I—LABORATORY STUDIES

FURNACE WITH OPPOSED FUEL AND AIR FLOWS

Flow-pattern studies having shown the marked entrainment by flame jets of the surrounding atmosphere, including recirculated flux-laden gases, the idea was conceived of a 'furnace with opposed fuel and air' (FOFA) in which the air entered the furnace from the opposite end to the flame and completely enveloped it, thus separating the refractory surfaces from the furnace gases by a moving layer of relatively clean air. The idea of opposition originated from the

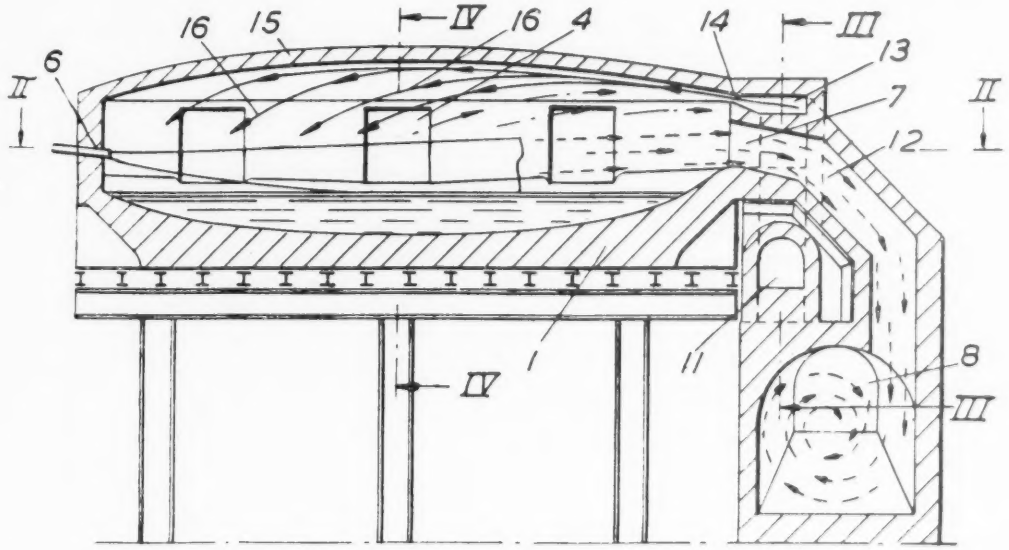

Fig. 1—Furnace with opposed fuel and air: vertical cross-section

observation that since, no matter what precautions were taken, the flame seemed to pull gas from the opposite end of the furnace, it should be allowed to do so but fed with air rather than with recirculated waste products. If such an idea proved practicable additional benefits would accrue, notably the cooling of the exit end (which tends to be hottest once charging has finished) by relatively cool air, which in turn would increase in temperature and, therefore, lead to higher radiation levels at the incoming end. This concept, which was covered by British, French, German, and U.S. patents,[2] is illustrated in Figs. 1–4.

The general idea is illustrated by Figs. 1 and 2, which represent vertical and horizontal sections through a furnace of this type. It will be seen that in this particular arrangement the air is introduced at the exit end of the furnace through a horseshoe aperture, that is concentric with the exit flue. Furthermore, the air is designed to sweep not only over the whole of the roof surface but also over the side walls. The sketches are, of course, purely diagrammatic, being merely a particular embodiment of the general idea, the development of which would require detailed attention to such points as the air distribution from the horseshoe duct (Fig. 3) which without special precautions is likely to be somewhat irregular.

Figure 4 merely shows the distribution hoped for at a central transverse section, the flame (17) and the contaminated atmosphere (18) above it being separated from the roof by the air sheet (19). It was realized even at the time of the patent application that the production of a layer of air moving smoothly from one end of the furnace to the other was somewhat optimistic and, therefore, the possibility of introducing part of the air through a series of additional slots or holes at intervals along the roof was included.

Simple water models having shown the possibility of producing a flow pattern of this general type, it was decided to construct a hot model of the furnace using high-temperature insulating bricks. Figure 5, which is a photograph of the first model built, unfortunately only shows the exterior, but it may be taken that the interior possessed essentially the lines given in Figs. 1–4. The furnace was fired with a Y type burner* (*see* left-hand side), while the air supply to the horseshoe duct can be seen entering the base of the furnace on the right-hand side. The location of the furnace (in a one-time bedroom!) prevented the design being followed completely, which explains why the waste gases, having been brought up from a lower level, are removed by means of an ejector through a hole in the window. After only minor adjustments the model furnace performed in the manner hoped for and appeared superficially to be quite satisfactory.

* Kindly supplied by the Shell Petroleum Co., Ltd.

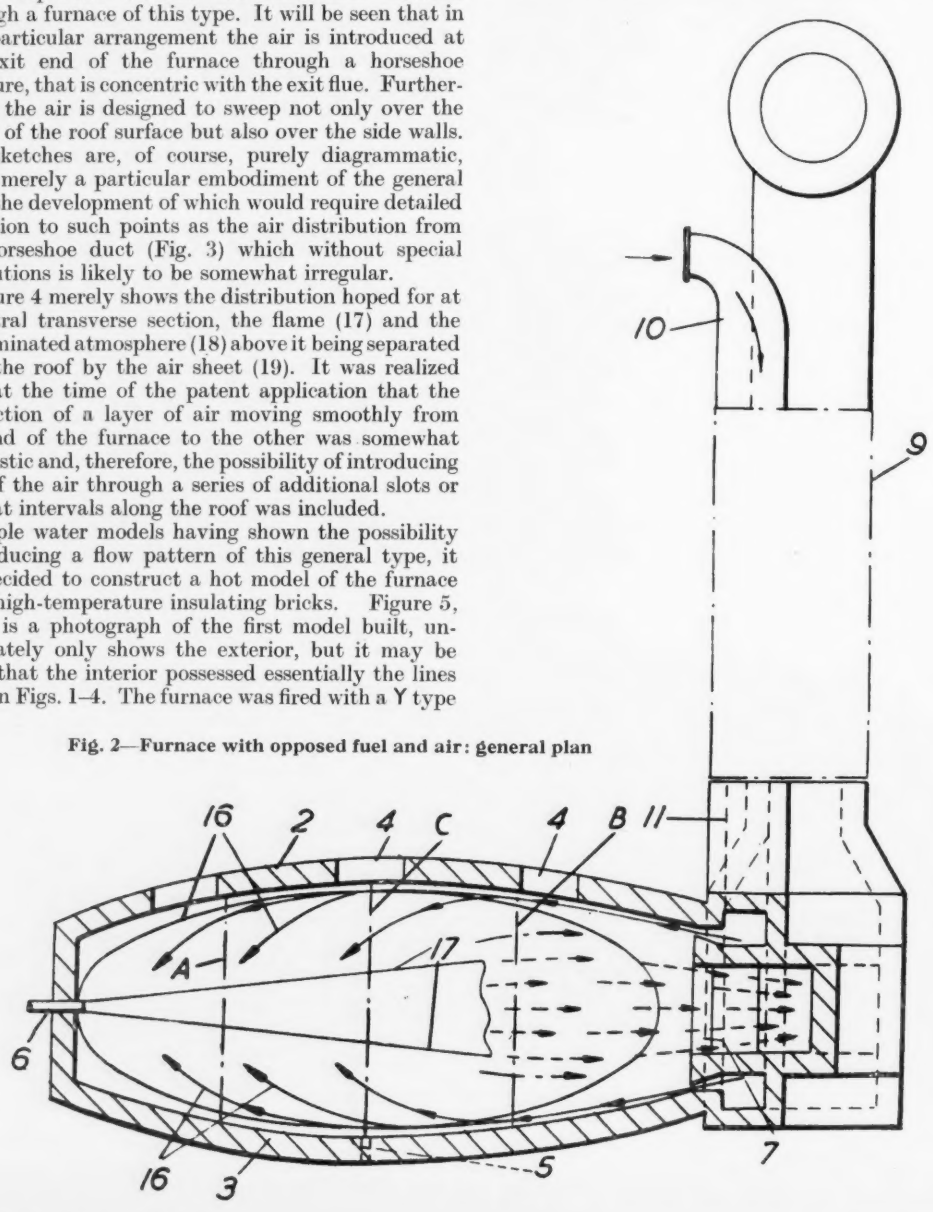

Fig. 2—Furnace with opposed fuel and air: general plan

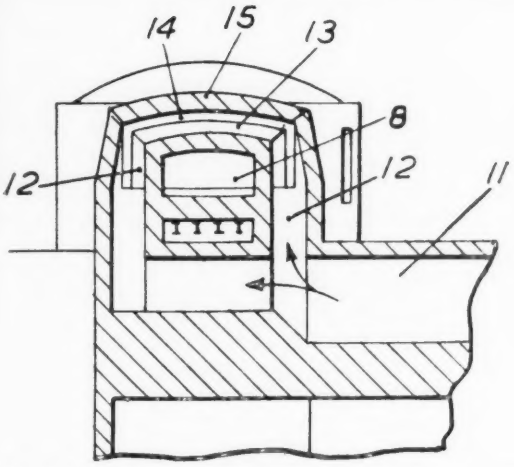

Fig. 3—Furnace with opposed fuel and air: vertical section through exit end

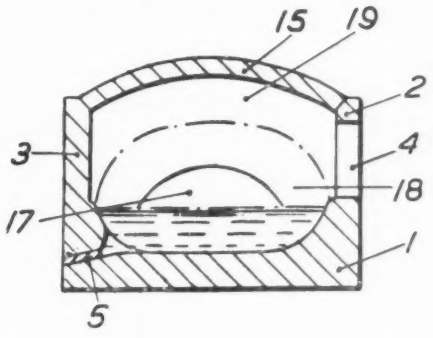

Fig. 4—Furnace with opposed fuel and air: vertical section across furnace centre

After considerable data had been collected, for example on temperature distribution throughout the structure (*see* thermocouple connection board), a rather surprising phenomenon was observed, due to a bevelled roof brick having been accidentally replaced in the structure the wrong way round. The result—the cause of which was not at first identified—was that the furnace refused to light. Every time a pilot flame was introduced it merely emitted a loud rumbling noise. Examination of the interior showed that the offending roof brick was protruding $\frac{1}{2}$ in. or so below the curved surface of the roof. When it had been replaced correctly, the furnace lit without trouble and heated up in the normal manner. Checks of the flow pattern on the actual furnace in the cold condition (*see* Fig. 6) showed it to be essentially that desired, but any protuberance from the roof, such as the brick mentioned above, led to a complete change of flow pattern, the incoming air turning downwards towards the bath and the fuel stream rolling on it in such a way as to prevent the two streams from mixing satisfactorily. This led to the realization that such a furnace correctly designed and built might operate with a level bath but might become unstable when charged with a pile of scrap. Simulation of this latter condition, by placing brick ends in the model furnace, strengthened the fear.

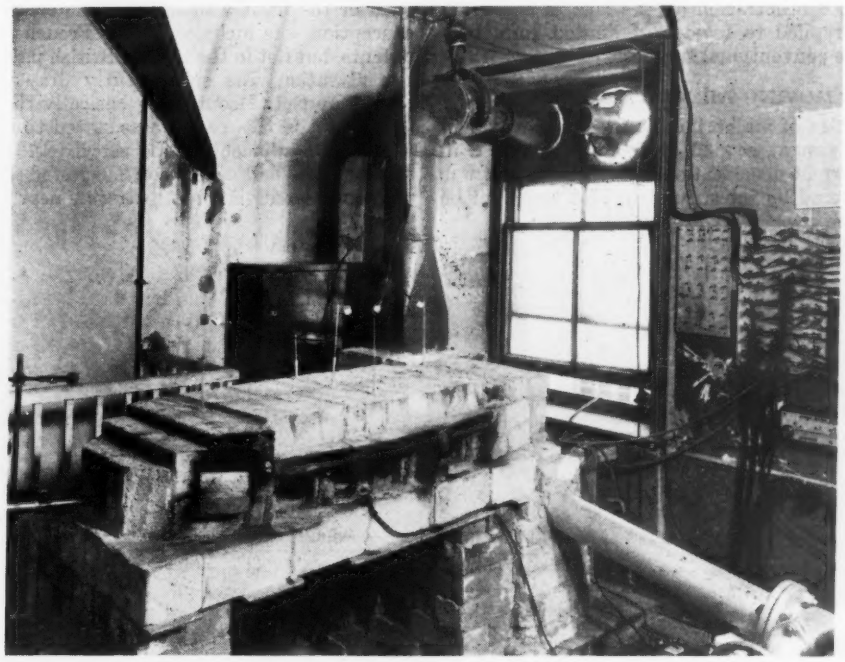

Fig. 5—External view of model furnace with opposed fuel and air

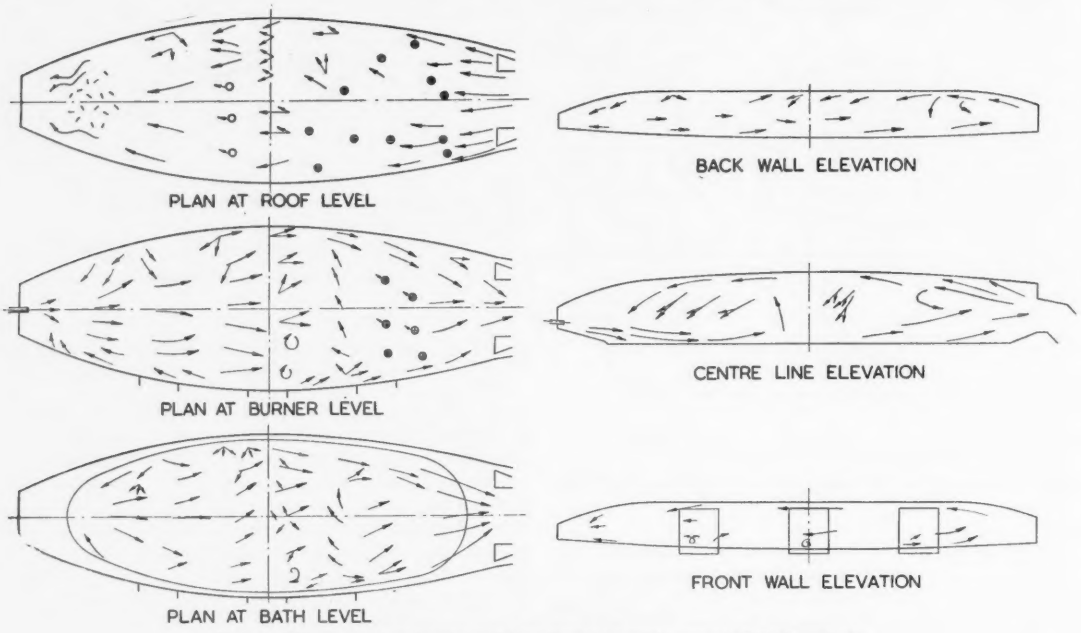

Fig. 6—Flow pattern in the cold on furnace with opposed fuel and air

The relatively unstable flow pattern, combined with the realization that any simple application of the idea would necessitate the use either of a high-temperature recuperator (instead of checkers) or of valves capable of operating at temperatures up to 1500° C, led to re-orientation of the research, and in particular to concentration on the idea of a moving air curtain applied to regions of limited refractory areas in more conventional furnaces.

MOVING AIR CURTAINS

The difficulty of maintaining a moving air curtain over long distances, say 30–50 ft, was recognized in the above patent specifications (*see* Fig. 7) and was partially covered by the suggestion that air might be introduced in two, three, or more stages along the roof, as it is, for example, in the walls of a jet engine, where so-called ' skin cooling ' is a recognized design feature. The alternative idea, first suggested to us by Mr. I. M. D. Halliday, was the use of a transverse air curtain running just beneath the roof from the back or the front wall towards the centre-line. This conception was included in the French and German patents, but not in the U.S. or British patents because our attention was subsequently drawn to a U.S. patent by Getz,[3] containing basically the same idea. The object in this patent was stated to be cooling of the regions adjacent to the skewback. A somewhat similar idea had also been suggested by Morgan,[4] who considered that roof guttering near the backwall

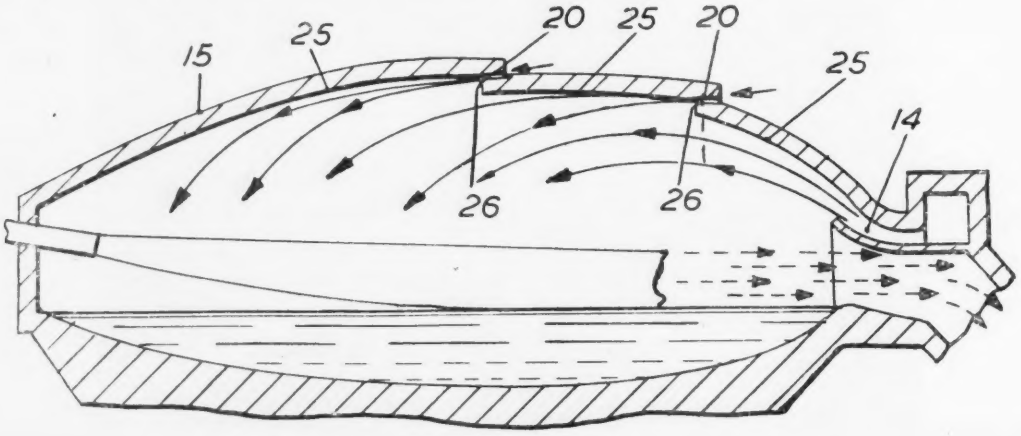

Fig. 7—Furnace with opposed fuel and air fitted with additional curtains

was due to deviation of the flame when the doors were opened and, therefore, suggested " the provision of means, operated in unison with the furnace charging door or doors, which supply a flow of air or inert gas into the furnace which cools the roof adjacent to the backwall or lining and tends to keep the burning gas down on to the bath of the furnace." In the diagrams shown the number of entry points is strictly limited. Their use might result in local cooling but would also undoubtedly cause new entrainment and only very localized protection. Incidentally, the idea that it is the opening of doors which causes guttering was fairly widely held but is neither obvious to the eye nor necessary to explain guttering in view of the work done in recent years on flow patterns, mixing, and oxide deposition.

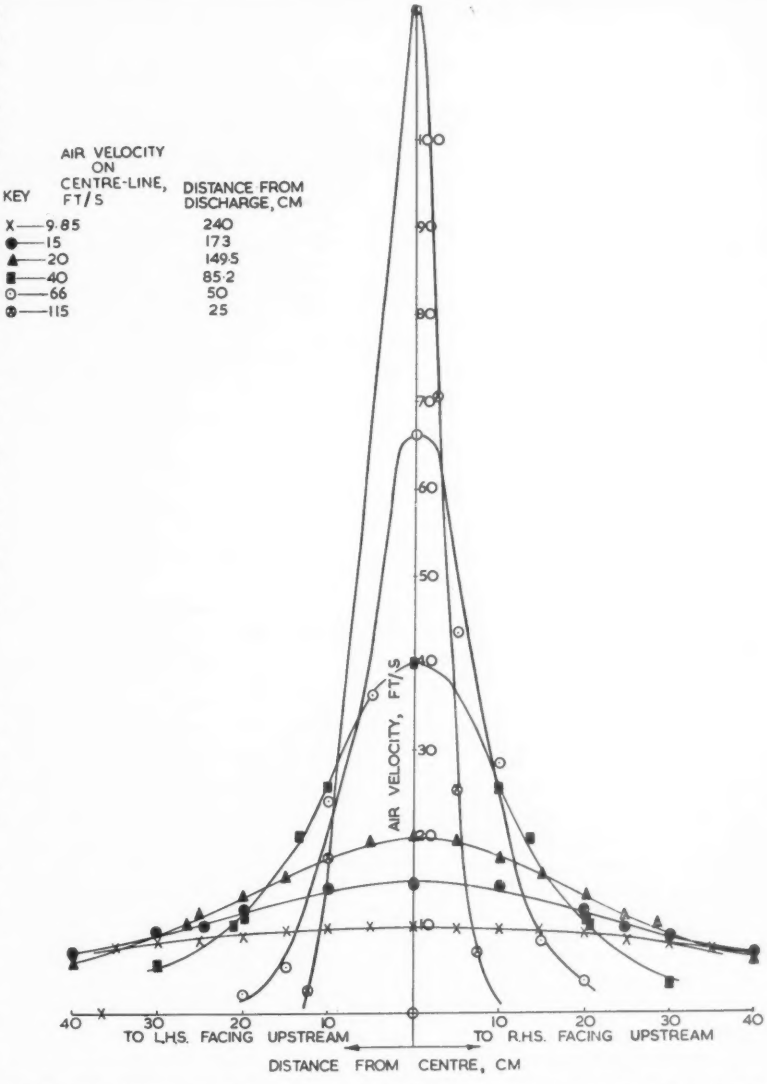

Fig. 8—Velocity profile for single round orifice with stream projected parallel to surface

Development Stages

The object of the present studies was the production of a curtain of air or other incombustible gas beneath the roof, so arranged as to minimize entrainment of furnace gases and thus provide

(*a*) A low concentration of fluxes
(*b*) A somewhat lower temperature
(*c*) An oxidizing atmosphere,

all three of which should reduce attack on silica refractories.

Incidentally, work published elsewhere[5] shows a strong tendency for these three conditions to be present simultaneously, the explanation being that the fluxes are picked up from the bath by the moving flame gases and if, therefore, the latter reach the roof level before they are completely burned, a high temperature due to continued combustion, reducing gases, and a high concentration of fluxes due to the relatively small amount of dilution may be expected.

Free Jet

When air or other gas is blown out through a tube or through a hole in a plate, a so-called ' free jet ' is produced. A knowledge of the behaviour of such jets is of the utmost importance both in connection with the mixing of fuel with air in furnaces and with the use of air jets to give local protection. The development of a free jet may be broken down for convenience into two regions:

(*a*) An initial one, in which vigorous entrainment occurs of the secondary fluid surrounding the unmixed core of primary fluid; the latter only disappears at about 4 to 8 diameters from the orifice.
(*b*) A transition zone followed by full development of the free jet at a distance about 10 diameters from the outlet, at which point the jet boundary expands at a total angle of roughly 20° owing to turbulent mixing with the surrounding fluid.

As would be expected from the law of constant momentum, the increase in the mass flow of the jet with distance is associated with a fall in velocity. Theoretical expressions have been developed, and confirmed by experiment, to relate the total flow at a

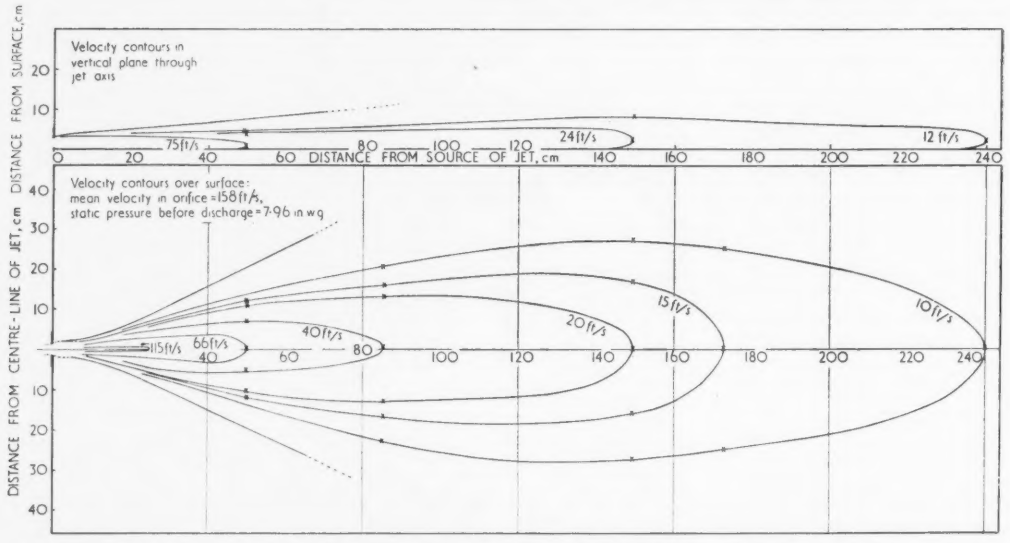

Fig. 9—Velocity profiles (vertical and horizontal) for single-orifice jet blown over flat surface

given point in a fully developed jet to the flow discharge rate at the orifice. Such calculations and experiments show that a free jet formed from, say, a 1-in. dia. orifice entrains approximately seven times the primary flow within a travel of only 2 ft, while its maximum velocity falls in the same distance to only a quarter of that at the outlet.

Jets Blown Over Surfaces

Single Jets—In these experiments air jets from a 2·5-cm dia. orifice and from a $\frac{1}{4}$-in. rectangular slot of the same area were directed over a plane wooden surface 3 ft wide and 8 ft long, set with its leading edge $\frac{1}{16}$ in. below the lower edge of the aperture. The jets were examined for each aperture with the plane set both parallel to the jet axis and at an impinging angle of 15° to the direction of discharge. A metered flow of 50 ft³/min, giving an exit velocity from the aperture of 158 ft/s, was used throughout the tests. The velocities within the jet boundaries were measured with a total-head tube, assuming the static head to be zero. Measurements taken with a pitot-static tube along the jet confirmed that the error resulting from this practice was negligible at distances of 5 cm or more from the orifice. In the initial studies lycopodium powder sprinkled over the surface was used to delineate the jet contour.

In subsequent and more precise studies velocity profiles were constructed from the total-head readings from each jet at suitable distances from the source. The boundaries of the jet were found by the zero velocity method using the total-head tube. Beyond

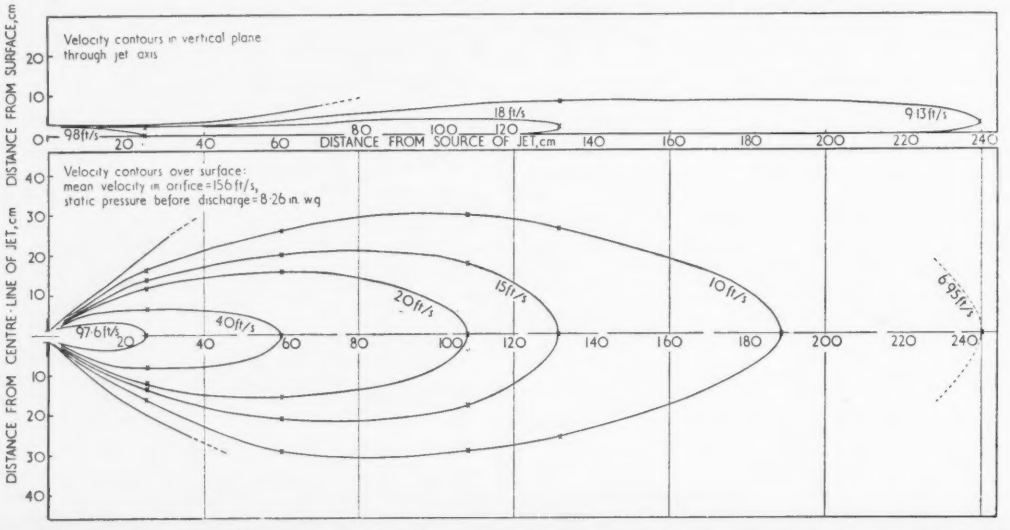

Fig. 10—Velocity profiles (vertical and horizontal) for single orifice jet impinging on flat surface at 15°

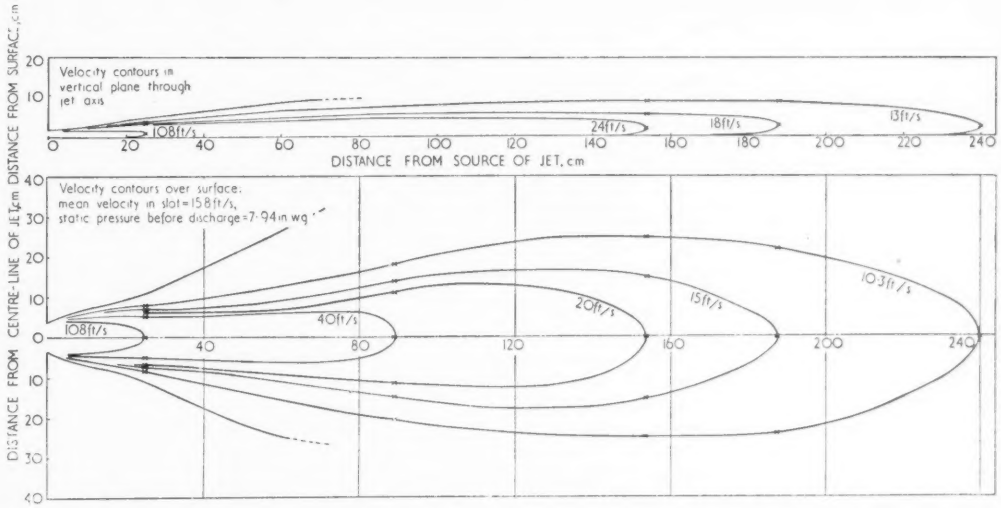

Fig. 11—Velocity profiles (vertical and horizontal) for jet from ¼ in. rectangular slot with surface parallel to jet axis

a certain distance from the discharge the measurable boundary developed into a zone of general turbulence, and could not be located with any degree of accuracy by this method.

Figure 8 shows the velocity profiles for a jet from a single round orifice projected parallel to the surface. Near to the orifice there is a very steep velocity gradient and as the distance from the orifice increases this flattens out until at roughly 100 times the orifice diameter the region for 40 cm on either side of the jet axis is covered by a substantially uniform-velocity moving air curtain. This pattern and the velocity contour shown in Fig. 9 are characteristic of the whole problem, the subsequent patterns obtained with multiple jets and slots being related to these basic distributions.

If now the jet is inclined at an angle of 15° to the surface, the jet tends to 'splash,' showing the broadened patterns in Fig. 10. Further steepening of the angle increases the spread until with a vertical jet the contours consist of a series of circles around the jet axis.

The pattern obtained with a jet from a ¼-in. slot blown parallel to the surface is shown in Fig. 11. This is similar to that given by a circular orifice, but the initial coverage is considerably greater. Inclination of the slot jet at 15° to the surface results in further broadening.

Table I

SUMMARY OF GENERAL DATA FOR FLOW FROM SINGLE ORIFICES OVER SURFACES

	Circular Orifice		Rectangular Slot	
	Parallel Plane	Inclined Plane	Parallel Plane	Inclined Plane
(1) Average metered velocity at discharge, ft/s	158	158	158	158
(2) Discharge velocity as measured with pitot tube, ft/s	166	...	175	...
(3) Static head before discharge, in. w.g.	7·96	8·26	7·94	7·94
(4) Angle of boundary divergence across surface	50°	68°	50°	53·5°
(5) Distance of apex of angle from discharge	7 cm downstream	5 cm upstream	At discharge	15 cm upstream
(6) Vertical boundary angle measured from surface at centre-line of jet	5°	2·5° to 9·5° (6° average)	6°	5°
(7) Surface velocity at 7 ft 10½ in. from discharge on centre-line, ft/s	10·0	7·0	10·3	9·4
(8) Max. velocity in vertical plane through centre-line at 7 ft 10½ in., ft/s	12·0	9·1	13·0	12·0
(9) Distance of max. velocity above surface, cm	2·0	2·4	2·0	2·1
(10) Distance from discharge of surface velocities on centre-line, cm				
10 ft/s	240	188·5	240 (approx.)	< 240
15 ft/s	173	131·5	188	176·5
20 ft/s	149·5	108	154	144
40 ft/s	85	60	89	88

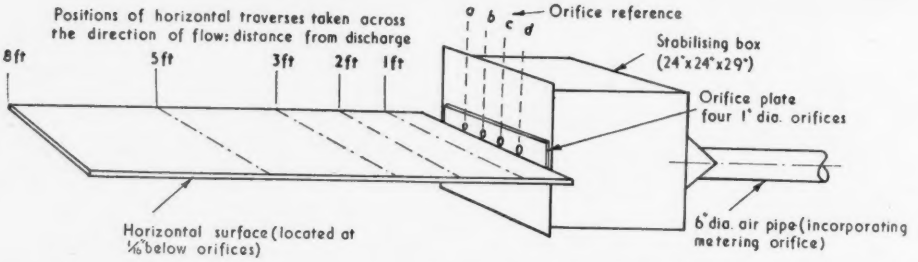

Fig. 12—Experimental apparatus for studying flow from multiple orifices over flat surface

The quantitative measurements made have been summarized in Table I; this shows that the vertical boundary angle measured from the surface at the centre-line of the jet is markedly less than with the free jet described in the previous section and the maximum velocity is within 1 in. of the solid surface. The distance at which the velocity drops to a given value, say 20 ft/s, varies appreciably from one arrangement to the other, though not as much as anticipated. Thus the 20-ft/s level is reached both with the circular and rectangular slot (parallel to the surface) at about 150 cm but appreciably earlier with the circular orifice at 15°. Of the arrangements tested the rectangular slot set parallel to the surface would seem to give the best protection.

Multiple Jets—From the information given above it is clear that full protection of a surface requires the use of multiple jets or a continuous slot. A series of experiments were therefore carried out to estimate the coverage with a row of four 2·5-cm dia. orifices, or alternatively four $\frac{1}{4}$-in. rectangular orifices of the same area. As in the single-jet experiments the surface was located $\frac{1}{16}$ in. below the bottom of the jet, but a second series 1 in. below were also carried out. The flow rates used were 100 and 200 ft³/min.

In order to obtain equal flow through each of the orifices, the flow from a 6-in. delivery pipe, containing a metering orifice, was first supplied to a 24 in. × 24 in. × 29 in. stabilizing box. The general arrangement is shown in Fig. 12, while detailed dimensions of the orifice and slot arrangements are given in Fig. 13. The numerous velocity measurements required were made with a rake of $\frac{3}{16}$-in. o.d. total-head tubes spaced at 3-in. intervals, readings being taken at distances of 1 ft, 2 ft, 3 ft, 5 ft, and 8 ft from the discharge orifices. Static head traverses were also made along the direction of the flow between orifices *B* and *C* in Fig. 12, and also opposite orifice *C*.

Typical velocity data for one arrangement—the four 1-in. dia. orifices with the surface $\frac{1}{16}$ in. below them and an air flow of 200 ft³/min—are given in Fig. 14. The rather elegant result is clearly related to the flow from individual orifices as examined above, and as the curtain moves away from the discharge points it gradually evens out to form a sheet of air moving at a relatively uniform velocity. At a point 1 ft away, however, the individual jets remain almost discrete. The horizontal velocity contours for this arrangement, for lower flows, and for the corresponding data on 3 in. × $\frac{1}{4}$ in. slots are shown in Fig. 15, which shows that the slot series comes closest to providing a uniform velocity front. The velocity contours in a vertical plane are summarized for similar arrangements in Fig. 16.

A new technique, viz. the production of patterns by spraying ink into the atmosphere above the surface to be protected, was used to show up the areas of effective coverage. The result obtained with one arrangement of four circular orifices is shown in

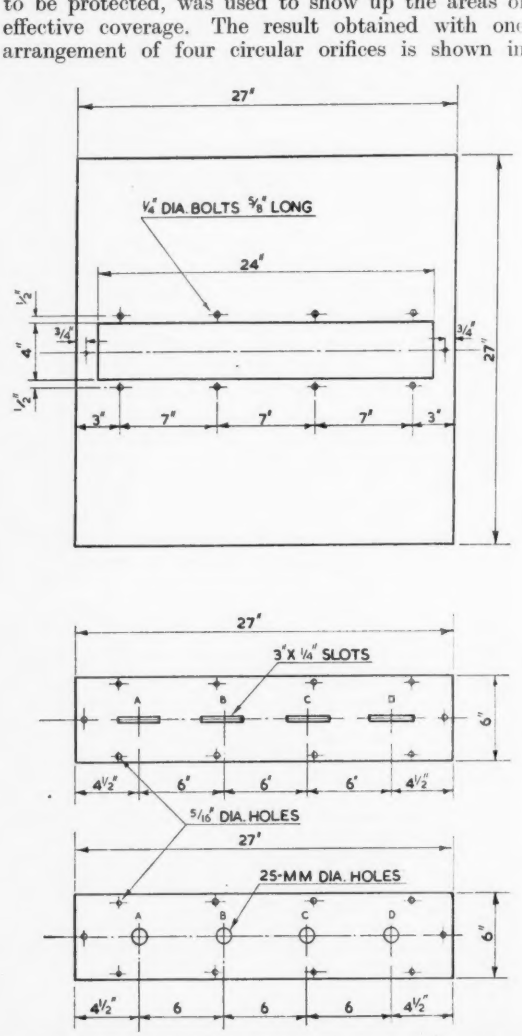

Fig. 13—Details of face-plate and discharge orifice plates

Fig. 17. Under these rather torrential conditions only relatively narrow strips on the axes of the main jets remain protected and—most interesting—the edges of the jet become areas of intense deposition, an effect which had already been observed in practice (*see* Part II—Works Trials) on an actual furnace where a furrowed type of wear had been observed. Similar patterns made with 3 in. × ¼ in. slots showed the fully protected area to be far greater—roughly that of the slot width itself. Determinations of the angle between the jet axes at discharge and the boundary of the air curtain gave values varying from 6° to 10°, i.e. about one-half that of a free jet.

The Continuous Slot—Tests were also made on a 21 in. × ¼ in. slot orifice with a view to obtaining even better velocity distribution. The slot was cut in a steel plate bolted to the face-plate of a stabilizing box, the lower edge of the slot being $\frac{1}{16}$ in. above the horizontal surface. The velocity distribution over this surface was again measured by a rake of total-head tubes and an air supply rate of 200 ft³/min. The results are shown graphically in Fig. 18, for various positions from the orifice and for heights varying from ¼ in. to 4 in. above the surface. Vertical traverses and air entrainment ratios were also measured.

Figure 18 shows that relatively flat velocity profiles were obtained, the undulations previously observed with multiple orifices being eliminated. Near the slot there are two small peaks of velocity at the lateral edges of the jet, probably due to three-dimensional entrainment in these regions. The entrainment for such an arrangement (per unit volume of air discharged) was found to be less than that given by a series of smaller orifices at similar velocities.

Flared Jet Bricks—The use in an actual furnace of sharp-edged slot-type orifices presents considerable difficulty, and so an attempt was made to see whether similar results could be obtained by means of a row of bricks having a hole through them which was slot-shaped at the working end and changed gradually to a circular orifice at the other end. The actual shape of the hole could be likened to a flattened trumpet, the mouthpiece of which was 1½ in. in diameter and the broad end flattened to 3 in. × ½ in. A series of bricks of this type were made up in plaster

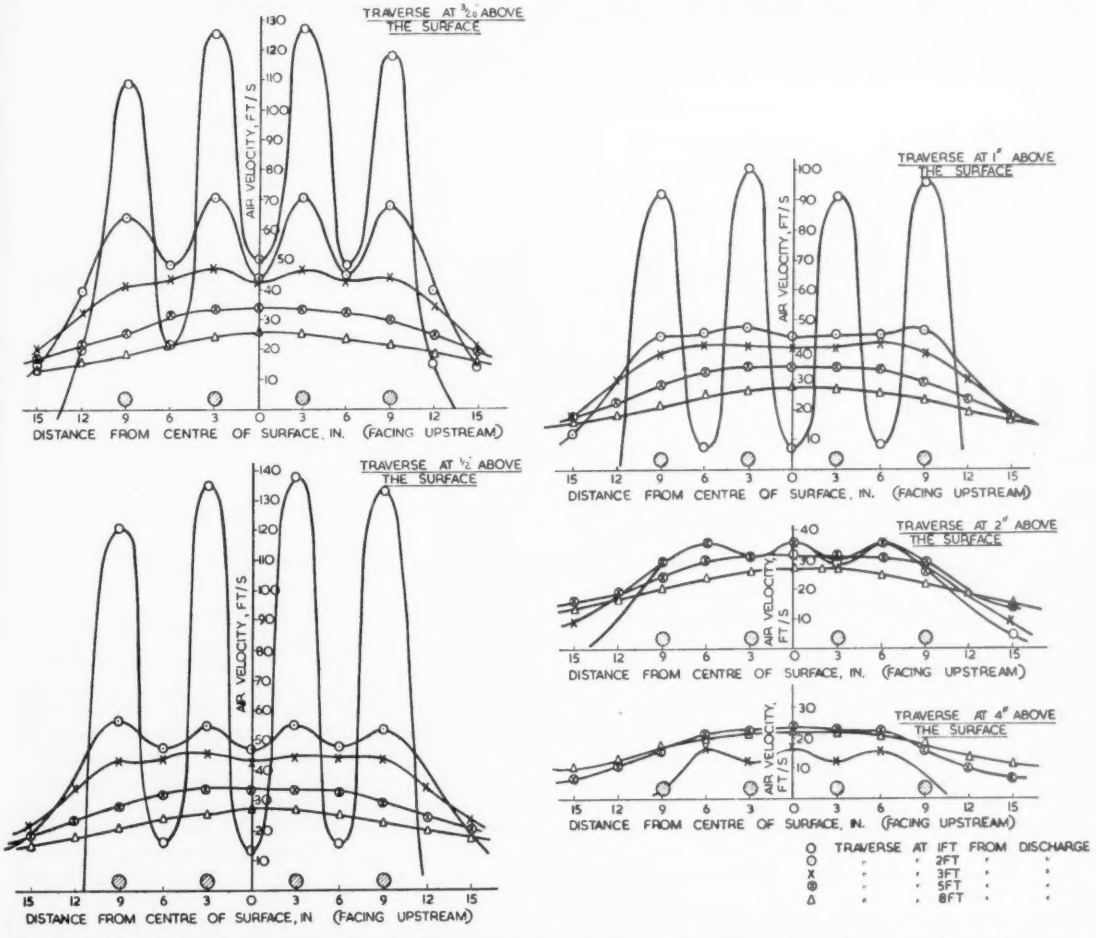
TRAVERSE AT 3/16" ABOVE THE SURFACE
TRAVERSE AT 1" ABOVE THE SURFACE
TRAVERSE AT ½" ABOVE THE SURFACE
TRAVERSE AT 2" ABOVE THE SURFACE
TRAVERSE AT 4" ABOVE THE SURFACE
AIR VELOCITY, FT/S
DISTANCE FROM CENTRE OF SURFACE, IN. (FACING UPSTREAM)
O TRAVERSE AT 1FT FROM DISCHARGE
O " " 2FT " "
X " " 3FT " "
⊗ " " 5FT " "
Δ " " 8FT " "

Fig. 14—Air flow over surface set parallel to direction of discharge surface $\frac{1}{16}$ in. below orifice. Horizontal traverses across direction of flow. Total air flow 200 ft³/min through four 1-in. dia. orifices.

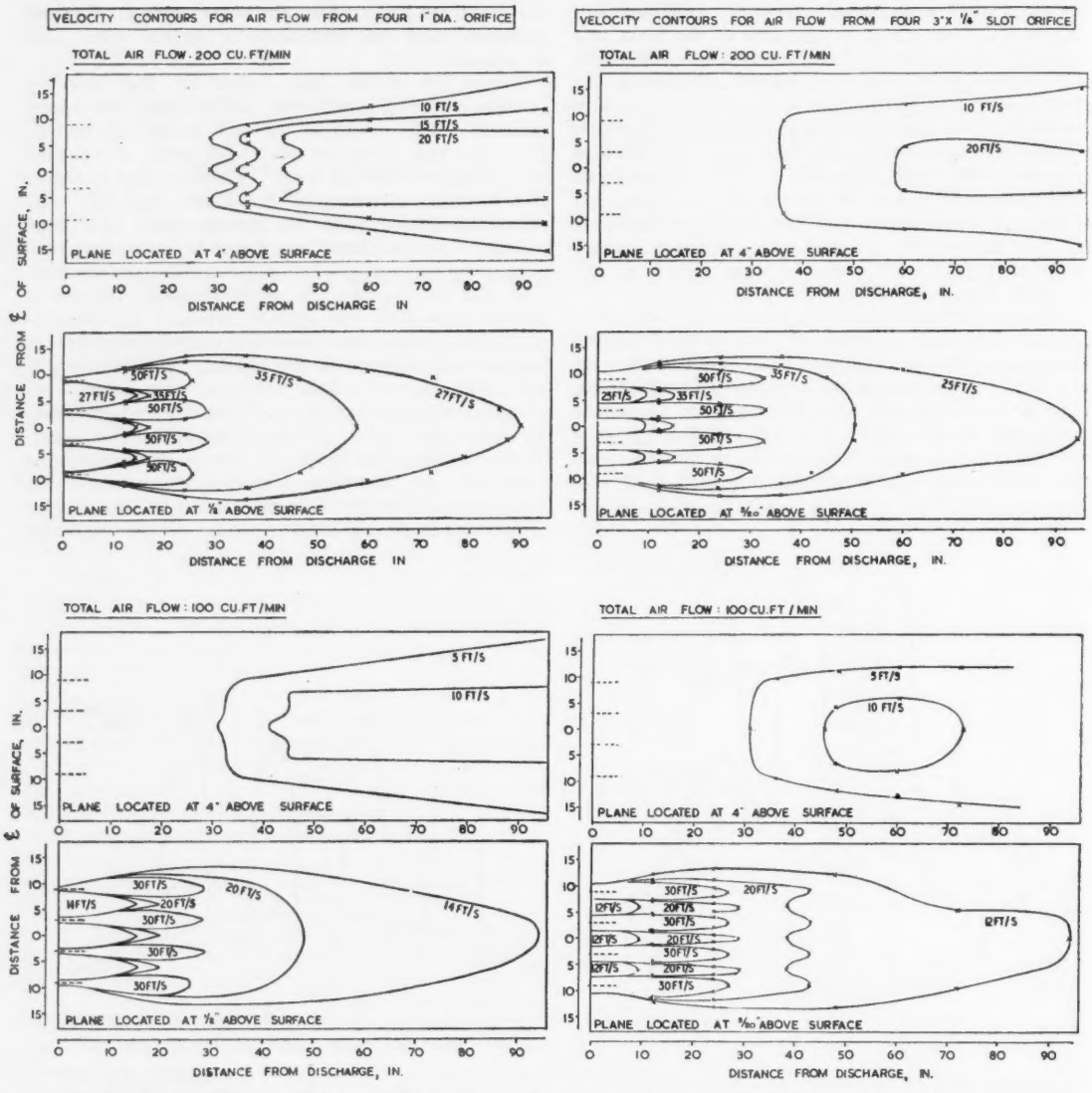

Fig. 15—Multiple orifices and slots: velocity contours through planes located above and parallel to surface

and were assembled edge to edge, leaving a distance of only 1 in. between the ends of adjacent slots, as compared with 3 in. in the earlier trials on a slotted steel plate. The circular ends of the holes were connected to a stabilizing box by four $1\frac{1}{2}$-in. steel tubes. As in previous experiments the horizontal plane surface was located $\frac{1}{16}$ in. below the slots and air flows of 200 ft^3/min were used. The results of velocity traverses are shown diagrammatically in Fig. 19. Vertical velocity traverses and air entrainment determinations were also made. Figure 19 shows that the undulating velocity profiles previously obtained with a row of slots were no longer present but that there were two maxima in the test made, $\frac{1}{4}$ in. above the surface.

Use of Hood and Inspiration Gap—One method of obtaining a sheet of air would be to blow from a series of orifices into an expansion box having a slot-shaped exit—formed in practice by leaving a suitably shaped gap between the top of the backwall and the undersurface of the roof. Studies were made in the laboratory of such an arrangement using four 1-in. dia. nozzles, blowing into a Perspex hood, the slot-shaped exit from which could be varied in height. It was found that stability of moving air curtains produced with such an arrangement could be greatly increased if air were allowed to enter through a slot at the entry side of the hood (an 'entrainment' or 'inspiration' gap). With a 1-in. high exit slot and a 1-in. high entrainment gap good conditions were obtained and trials were therefore recommended on a working furnace.

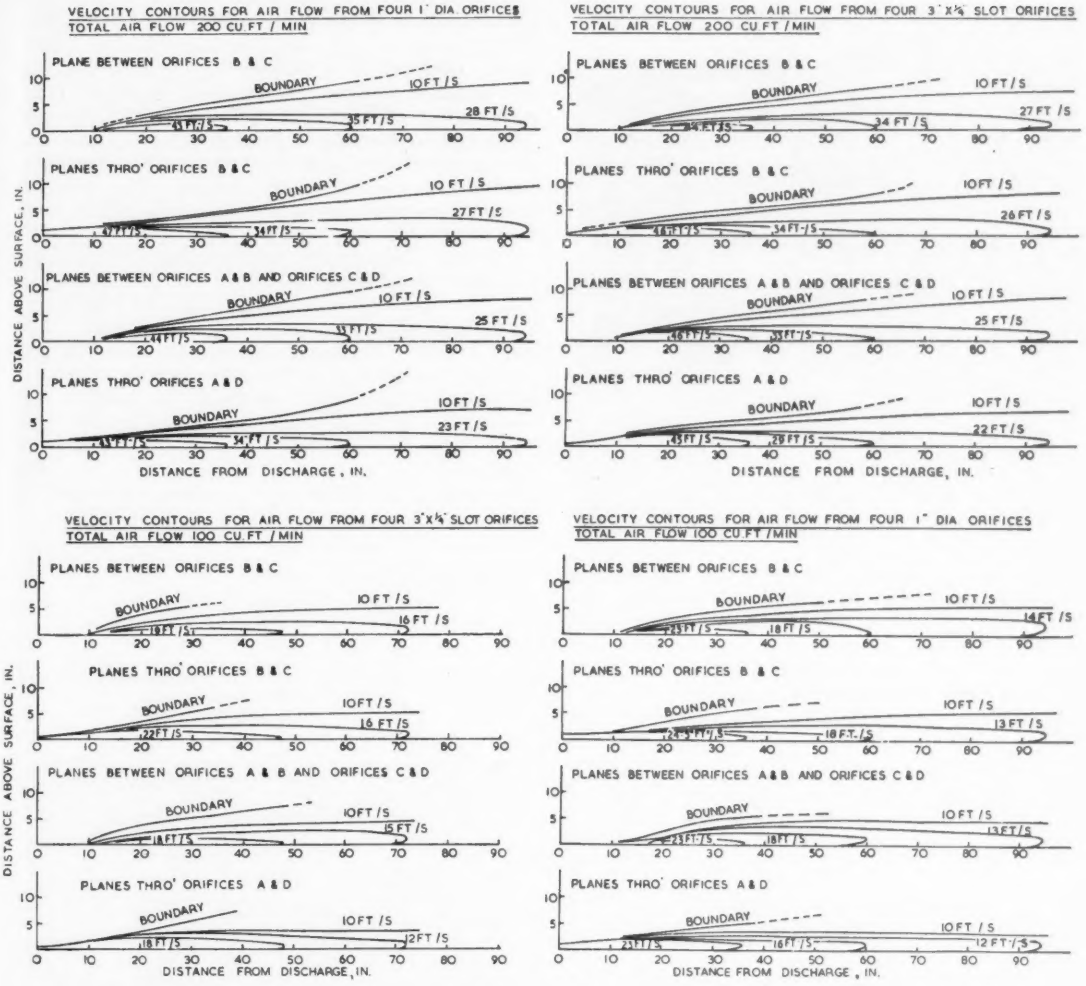
VELOCITY CONTOURS FOR AIR FLOW FROM FOUR 1" DIA. ORIFICES
TOTAL AIR FLOW 200 CU.FT / MIN
VELOCITY CONTOURS FOR AIR FLOW FROM FOUR 3"X¼" SLOT ORIFICES
TOTAL AIR FLOW 200 CU.FT / MIN
PLANE BETWEEN ORIFICES B & C
PLANES THRO' ORIFICES B & C
PLANES BETWEEN ORIFICES A & B AND ORIFICES C & D
PLANES THRO' ORIFICES A & D
BOUNDARY
10 FT / S
28 FT / S
27 FT / S
25 FT / S
23 FT / S
26 FT / S
22 FT / S
DISTANCE ABOVE SURFACE, IN.
DISTANCE FROM DISCHARGE, IN.
VELOCITY CONTOURS FOR AIR FLOW FROM FOUR 3"X¼" SLOT ORIFICES
TOTAL AIR FLOW 100 CU.FT / MIN
VELOCITY CONTOURS FOR AIR FLOW FROM FOUR 1" DIA ORIFICES
TOTAL AIR FLOW 100 CU.FT / MIN
16 FT / S
15 FT / S
12 FT / S
14 FT / S
13 FT / S

Fig. 16—Multiple orifices and slots: velocity contours in vertical planes along the direction of flow

Comparison of Air Entrainment with Various Arrangements

The entrainment data for the tests mentioned above have been summarized in Fig. 20 as a function of distance from the orifice. In each case the air velocity in the orifice throat was of the same order. The ordinate (R) is defined as Q/Q_0, where Q is the total air flow at a distance of x in. from the orifice, and Q_0 is the air flow at the discharge.

The equations for various arrangements are as follows :

(*a*) Four 1-in. dia. orifices:
$$R = 0{\cdot}0887x + 4{\cdot}5$$
(*b*) Four 3 in. × ¼ in. slot orifices:
$$R = 0{\cdot}0887x + 4{\cdot}5$$
(*c*) One 21-in. × ¼ in. slot orifice:
$$R = 0{\cdot}0700x + 2{\cdot}6$$
(*d*) Four 3 in. × ½ in. flared-jet bricks:
$$R = 0{\cdot}0715x + 1{\cdot}0$$

The independent constant in these equations is a measure of the initial vigorous entrainment for a particular arrangement. The fact that this constant is unity for the flared-jet bricks suggests that the initial entrainment has been largely eliminated and that they might therefore be expected to provide a better moving air curtain than the arrangements previously tested.

Experiments with Full-size Roof Model

The puzzling results obtained in practical trials, as described in Part II of this report, led to experiments being made in the laboratory with a full-size roof model built in steel and fitted with a series of slotted bricks, as shown in Fig. 21. This model was used for two types of experiment, in the first of which aluminium dust was used to represent flux droplets in the O.H. furnace and intense slit illumination (with photography) to follow their trajectories. In the second type of experiment, sticky papers were attached at various points on the roof and the weight of dust adhering to them under various conditions

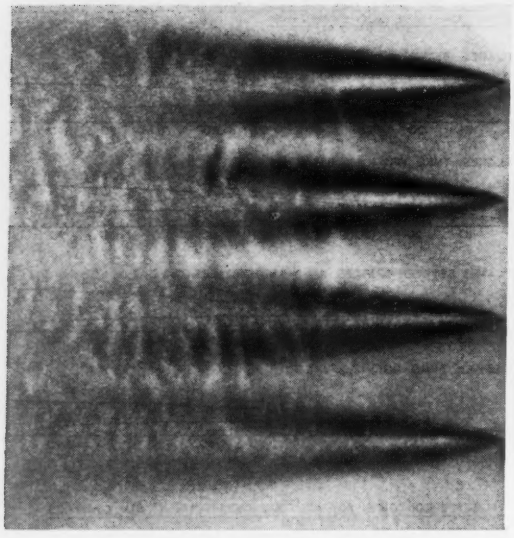

Fig. 17—Pattern obtained by spraying ink droplets on to surface protected by jets from four 1-in. dia. orifices. Total air flow 200 ft³/min; surface $\frac{1}{16}$ in. below orifice

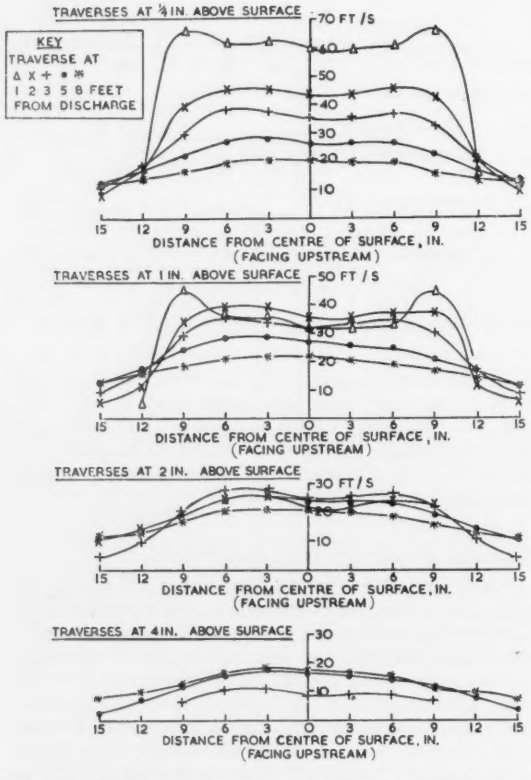

Fig. 18—Air flow over surface set parallel to direction of flow, continuous slot 21 in. × ¼ in. Horizontal velocity traverses across direction of flow. Surface set $\frac{1}{16}$ in. below slot. Total air flow 200 ft³/min

was compared. In the arrangement shown in Fig. 21, the stream of air from a small auxiliary fan was blown up the backwall at a velocity of about 12 ft/s, the best estimate available of the speed at which O.H. gases run up a backwall. The air velocities through the protecting curtain were varied and determinations were made of the extent of penetration by aluminium particles in the rising gas stream. The velocity distributions were determined by means of the pitot tube shown.

Particle Trajectories—Visualization of particles was made possible by the use of slit illumination, a flash of definite duration being obtained by discharging a bank of condensers across a flash tube. The sheet of light so formed intersected the backwall and roof in a vertical plane through the axis of one of six jet bricks used. The velocity of the particles was determined by their track length, calibration data for flash speeds being obtained by means of a rotating sector.

In certain of the experiments use was made of

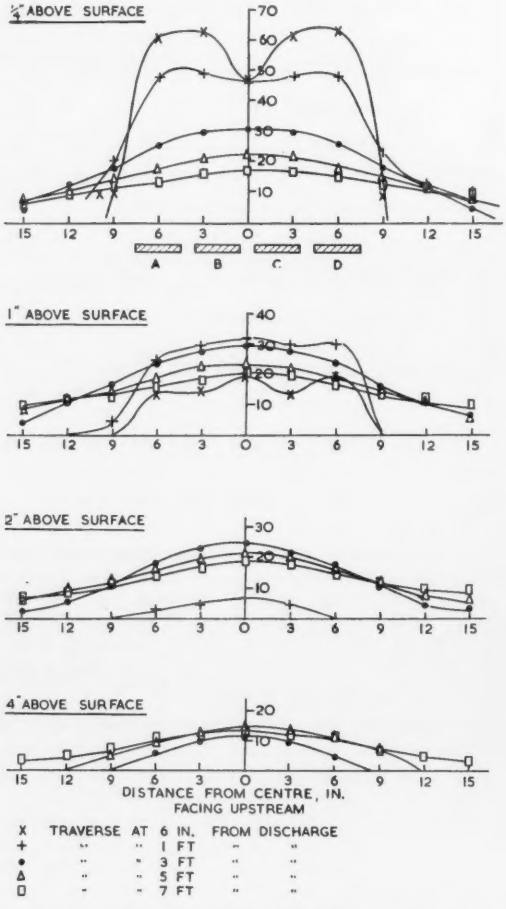

Fig. 19—Air flow over surface set parallel to direction of flow, using four flared-jet bricks. Horizontal velocity traverses across direction of flow

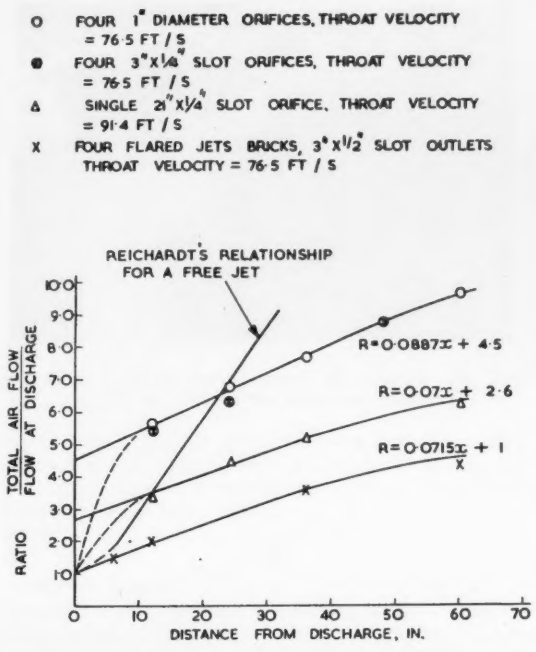
O FOUR 1" DIAMETER ORIFICES, THROAT VELOCITY = 76·5 FT / S
● FOUR 3"x1/8" SLOT ORIFICES, THROAT VELOCITY = 76·5 FT / S
Δ SINGLE 21"x1/4" SLOT ORIFICE, THROAT VELOCITY = 91·4 FT / S
X FOUR FLARED JETS BRICKS, 3"x1/2" SLOT OUTLETS THROAT VELOCITY = 76·5 FT / S
REICHARDT'S RELATIONSHIP FOR A FREE JET
R=0·0887x + 4·5
R=0·07x/a + 2·6
R=0·0715x/x + 1
RATIO TOTAL AIR FLOW / FLOW AT DISCHARGE
DISTANCE FROM DISCHARGE, IN.

Fig. 20—Comparison of air entrainment with jets from various types of orifice

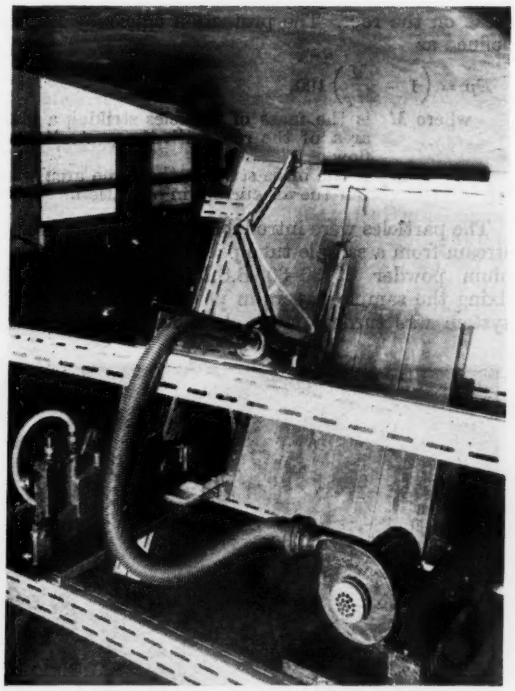

Fig. 21—Experimental arrangement for studying moving air curtain efficiency. Small fan supplies dust-laden air stream up sloping backwall

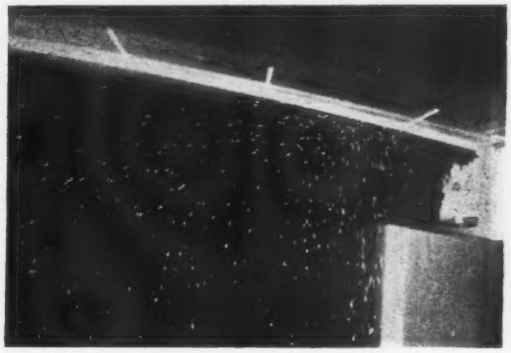

Fig. 22—Vertical air stream, with 30–60 mesh aluminium and no air curtain

a curved sheet of aluminium to simulate the corbelling out of the backwall with a view to reducing the sharpness of the turn and, therefore, the percentage of particles impacting on the roof.

The type of results obtained are well illustrated by Figs. 22–27. The first three show the results obtained with 30–60 B.S.I. mesh aluminium in the rising air stream and jet velocities of 0, 40, and 100 ft/s. In the arrangement shown the curved backwall is in use and a mixing ledge of $\frac{1}{16}$ in. depth between the bottom of the slot and the top of the backwall is employed. The slot bricks themselves are set with their top edge 1 in. below the roof surface. With no air on the curtain bricks the particles run up the wall and impact on the roof at a point within an inch or two of the backwall line. With 40 ft/s, most of them are deviated, but do penetrate the curtain and impact on the roof a few inches further away from the backwall. With 100 ft/s, impact is still further out but most of the particles do nevertheless penetrate the curtain. The number touching it will probably be less with still higher speeds but it should be noted these demand the use of large quantities of air through the slot bricks. In the present work a maximum volume equivalent to 5% of the combustion air was set, to avoid the risk of an appreciable decrease in fuel efficiency.

Fig. 23—Vertical air stream, with 30–60 mesh aluminium and with 40 ft/s air curtain from slots

Fig. 24—Vertical air stream, with 30–60 mesh aluminium and with 100 ft/s air curtain from slots

Fig. 26—Vertical air stream with paraffin smoke as tracer and with air curtain at 40 ft/s

In the second series of experiments the aluminium dust was replaced by paraffin smoke produced from an N.P.L.-type generator. It was thought this would simulate fairly accurately the finer fraction of iron-oxide fume in an O.H. furnace. Before the experiments were carried out it seemed obvious that material with such low inertia would be readily swept away from the roof by a moving air curtain having a velocity of, say, 100 ft/s. The results illustrated in Figs. 25–27 show, however, that this is by no means the case. With no air stream from the jets the smoke rises gently up the backwall and floats along the roof. With a jet speed of 40 ft/s, the first few inches of the roof are clear of fume, but after that impact appears to be at least as great as without the air jet system. Even with 100 ft/s, less than 1 ft width of the roof is cleared of smoke. The phenomenon having been observed, the explanation is, however, fairly clear: the fume is entrained by the jet stream and mixes with it by turbulent diffusion. Since even a jet from a plain orifice entrains roughly its own volume in moving eight diameters downstream, effects such as were observed with paraffin smoke should have been expected. Incidentally, the fact that a high-speed jet is passing under the roof may well cause more fume to rise towards it than would do otherwise, though this is offset at least in part by dilution with the jet air.

Velocity measurements made on the moving air curtain showed a tendency for the air stream to lift towards the roof surface. The actual velocity distribution clearly depends on the precise arrangements used, but with 100 ft/s jet speeds and zero backwall velocity, the velocity beneath the roof exceeds 30 ft/s, even 2 ft from the jet orifice.

The Sticky Paper Technique—Although the photographic method provides a valuable aid in designing new arrangements, it does not give any quantitative figure for the protection efficiency. A second method was therefore developed, in which a mixture of seven parts of castor oil and nine parts of resin was used to impregnate a filter paper and this sticky surface was employed to trap particles impinging on particular areas on the roof. The protection efficiency Ep was defined as

$$Ep = \left(1 - \frac{M}{M_T}\right) 100,$$

where M is the mass of particles striking a given area of the roof with the protecting air flow

M_T is the mass striking the same area without the air curtain in operation.

The particles were introduced into the backwall air stream from a sample tube packed with 4 g of aluminium powder of 30–60 B.S.I. mesh size. Before fixing the sample papers in position, the air for the system was turned on to clear out any aluminium

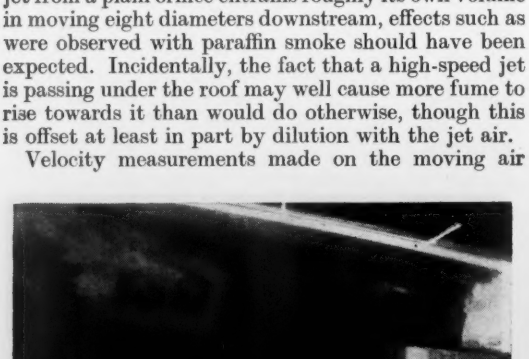

Fig. 25—Vertical air stream with paraffin smoke as tracer and no air curtain

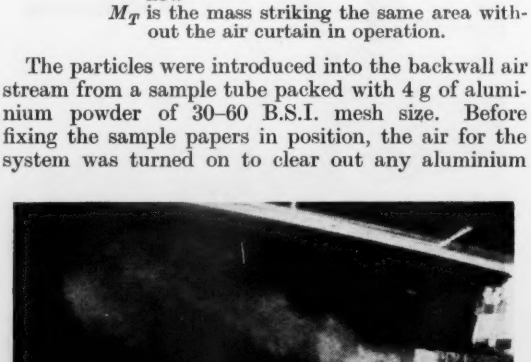

Fig. 27—Vertical air stream with paraffin smoke as tracer and with air curtain at 100 ft/s

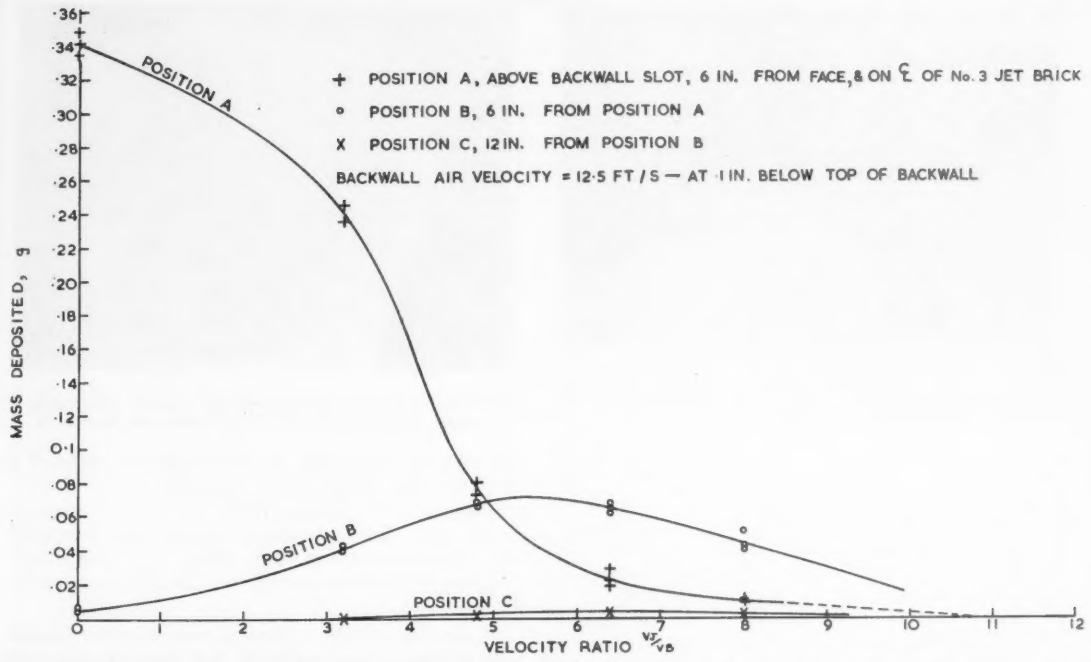
+ POSITION A, ABOVE BACKWALL SLOT, 6 IN. FROM FACE, & ON ℄ OF No. 3 JET BRICK
o POSITION B, 6 IN. FROM POSITION A
X POSITION C, 12 IN. FROM POSITION B
BACKWALL AIR VELOCITY = 12·5 FT/S — AT 1 IN. BELOW TOP OF BACKWALL
POSITION A
POSITION B
POSITION C
MASS DEPOSITED, g
VELOCITY RATIO Vj/VB

Fig. 28—Deposition of aluminium particles on model roof with varying velocity ratios, using air curtain with mixing ledge $\frac{1}{16}$ in. below slots

dust remaining from previous tests. In the series of trials described, three collecting areas were used: one immediately above the backwall (*A*), a second (*B*) 6 in. from *A*, and a third (*C*) 12 in. from *B*. The fans having been started, the sample was discharged into the steady air flows. The material adhering to a $2\frac{1}{2}$-in. square test section was washed off with benzene and the aluminium powder was dried and weighed.

The results obtained with this technique are well illustrated by Fig. 28, which shows that as the velocity ratio (jet to backwall) increased, the deposition immediately above the wall fell off, but that 6 in. further out it increased. The deposition 2 ft from the backwall was in all cases very slight. Even with such quantitative information, however, the prediction of probable wear is difficult, since there are still certain unknowns, notably the droplet size distribution of the O.H. furnace fume, the backwall velocity, and the amount of additional material brought up the wall owing to the entrainment action of the air curtain itself.

Other Arrangements

Numerous other arrangements have been suggested and several of these have been tested out in the laboratory. Brief notes on some of the more interesting ones are given below:

Backwall Corbelling—In order to get a quick impression of the effect of certain changes, such as corbelling of the backwall, two-dimensional water

Fig. 29—Two-dimensional water model showing flow up sloping backwall and impingement on roof in absence of air curtain

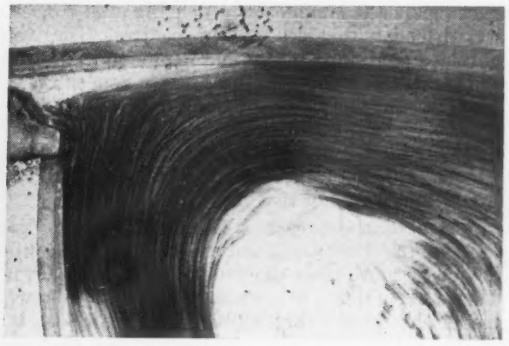

Fig. 30—Two-dimensional water model with air curtain having four times sloping backwall stream velocity

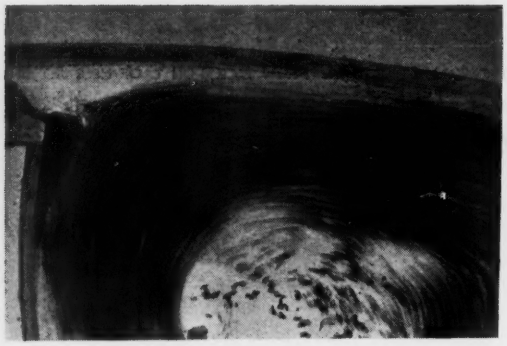

Fig. 31—Two-dimensional water model with air curtain having four times backwall stream velocity and top of backwall vertical

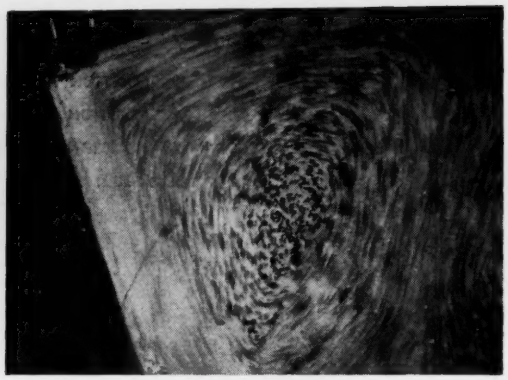

Fig. 32—Water model showing vortex produced by using air curtain projected down the backwall

models were used. Figures 29 and 30 show the results obtained with the normal backwall arrangement both with and without a moving air curtain, and Fig. 31 shows the marked improvement that can be obtained by increasing the angle between back wall and roof; the black wedge is a piece of Plasticine inserted to represent a vertical section for the last few feet of backwall, equivalent displacement on the furnace being 4 in. With the latter arrangement the area of clear water beneath the roof is markedly greater, though turbulent diffusion, probably of a type not shown by these models, may still occur. It was also found that the actual velocities of the two streams had very little effect on the flow pattern, it being the ratio between them that was important.

Horizontal Curtain—Since a moving sheet of air tends to entrain rising gases it was suggested that better results might be obtained with a horizontal curtain. Tests using the sticky paper technique showed a protection efficiency substantially greater than that obtained with tangential curtains and, as will be seen later, this led to trials of horizontal curtains on an actual furnace.

Perforated Roof—It was suggested that since perforated roofs had already been used in reheating furnaces, similar roofs might be tried as protection curtains, holes being placed at intervals over a roof section. Tests were therefore made, again with the sticky paper technique, in which the area concerned was drilled with holes at 3-in. centres. The results obtained were far from encouraging. Indeed, certain of the arrangements showed greater deposition than when no air was passing through the holes. This is probably again due to the entraining power of the individuals jets, which tends to draw to the root of the jet and, therefore, to the roof surface, material that would otherwise not reach it.

The Vertical Jet System—Since the offending gases rise up the backwall, one possible solution would obviously be to blow the protecting curtain down it. The result of doing this is clearly shown by the water model photograph (Fig. 32) which shows that a large vortex is formed which may well reduce the attack in regions adjacent to the backwall but increase it along a line further from the skewback. As the ratio of the vertically downward to the vertically upwards velocity was increased, the vortex merely speeded up without any change in general shape.

Diagonal Jet Systems—Water model tests were also made with jets introduced diagonally downwards from the skewback section. These showed a relative absence of particles in the roof area adjacent to the backwall.

Twin Jets—Since particles penetrate one moving air curtain quite readily, it was thought improved results might be obtained by having a ' half-back ' as well as a ' full-back ' to prevent the opponent reaching its goal. A fair measure of protection appeared to be obtainable in this way, though not as great as was shown by the diagonal jet system referred to above.

Low-velocity Curtain—Experiments were also carried out using the sticky paper technique with a low-velocity air box passing a relatively large volume of gas. Expressed on a velocity ratio basis, the protection efficiency obtained in this way was high, but unfortunately the amounts of air required were considered too great to warrant a service trial.

Part II—WORKS TRIALS

One of the unknown factors in applying the idea of moving air curtains was the extent to which the roof in the high-velocity region would be cooled by the air stream. Since no suitable data were available to enable the effect to be calculated, a preliminary trial was made in which a $\frac{3}{4}$-in. bore steel pipe, supplied with air from a compressor at 75 lb/in^2, was used to blow a jet of air on to the undersurface of a roof. The initial trial was done through an end wall, the jet being blown at an angle on to the ramp roof. Air was supplied at a rate of about 40 ft^3/s, and it was estimated that the velocity at a point 3 ft from the orifice would be 40 ft/s. The brickwork temperature, as measured with a disappearing filament pyrometer, was initially 1380° C, but when the end of the tube was brought within 6 in. of it and the air supplied at the above rate, it cooled rapidly to 1340° C and to an intermediate degree in the regions adjacent to the point of impact. In a subsequent test, in which an air lance was inserted through a pyrometer spy-hole in a backwall and the roof was initially at 1640° C, a similar degree of darkening occurred when the air was turned on. This degree of cooling

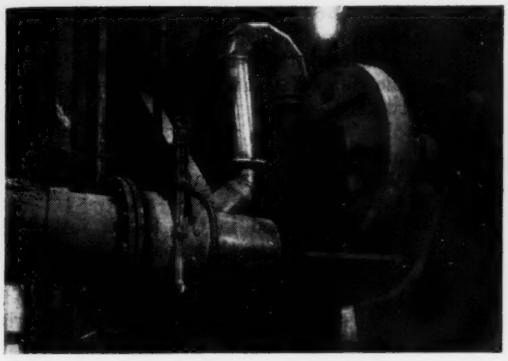

Fig. 33—Fan, gate valve, and bustle pipe of moving air curtain installation

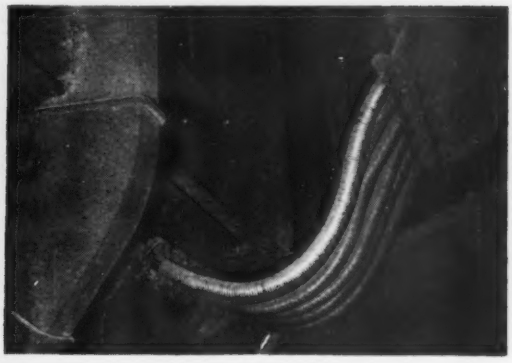

Fig. 34—Moving air curtain installation, showing bustle pipe and flexible metallic hose connections to jet bricks

would not be expected to give any appreciable thermal shock and would have the advantage of adding a reasonable amount of cooling to the cleansing effect of the jet.

AIR SUPPLY

The precise equipment used for supplying air to the moving air curtain varied with particular trials, but the general arrangement used at S. Fox and Co., Ltd., was relatively standard. It consisted of a fan, 7½ h.p. (used because available but several times as great as necessary), feeding a 12-in. dia. steel pipe running along the back of the furnace (*see* Fig. 33); from this were tapped as many 2-in. pipes as were required to feed the various points along the curtain (*see* Fig. 34). In the initial experiments 18 such pipes were used, spaced at 6-in. centres, and aimed to give protection along the 9-ft central section of the roof. The flow was metered by means of a standard orifice and manometer and controlled by a gate valve (*see* Fig. 33) fitted near to the fan. The pipes used for connecting the large main to the backwall tubes were of the flexible metallic type in order to avoid any strain on the brickwork due to differential movement. The large-size bustle pipe was chosen to ensure relatively even distribution of flow between the offtakes.

TRIALS OF 1-in. ORIFICES AT 6-in. CENTRES

In the initial trial, on *K* furnace at S. Fox and Co. Ltd., which started on 10th February, 1951, 18 1-in. refractory nozzles at 6-in. centres were placed along the top of the backwall and arranged to blow tangentially on to the roof. The volume of air used was initially 720 ft³/min, which was cut down after three weeks to 450 ft³/min. This is equivalent to an exit nozzle velocity of 122 ft/s—or, when cut down, to 76 ft/s.

The cooling effect of this curtain was quite obvious, as a series of dark stripes on the roof which disappeared when the fan was shut off. This uneven velocity distribution soon showed itself in a corresponding unevenness in roof wear, the areas in line with the jet axes being protected but those in between worn, if anything, more than normal. From the start the furnace seemed to drive faster than usual rather than slower, probably because, as was only discovered later, there was an appreciable cooling effect even at the roof centre. Since the curtain was only 9 ft long the ends were not affected and, since the furnace was operated in terms of a maximum roof temperature at the crown centre, this led to rather more fuel being burned and consequently hotter exit ends. The extent of the drop in temperature when the curtain was turned on was subsequently noted by repeated switching on and off of the curtain air fan and found to be only of the order of 10° C.

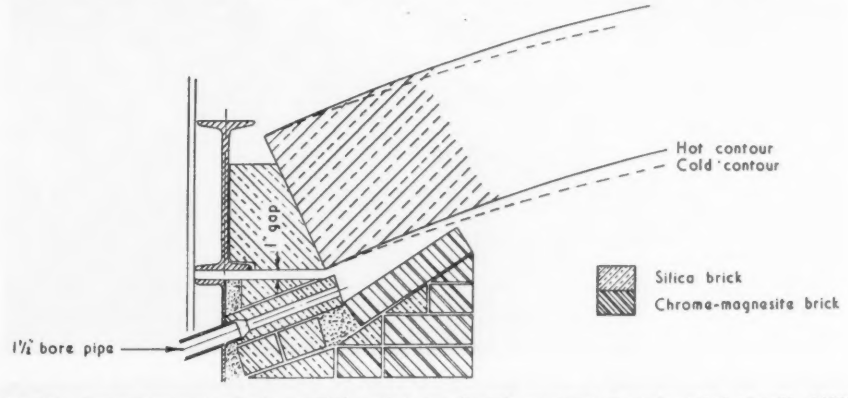

Fig. 35—Arrangement of air curtain slot on fourth moving curtain trial (April, 1951)

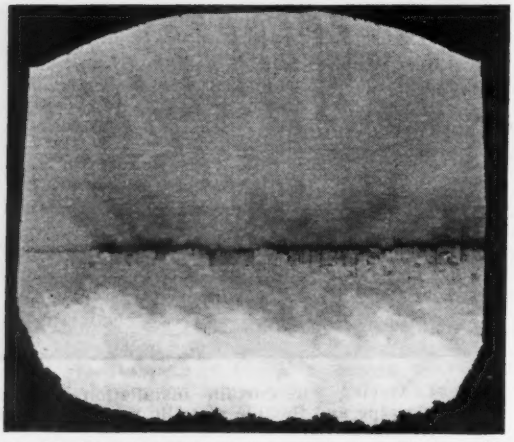

Fig. 36—Fourth moving air curtain installation after six weeks' operation. Air flow increased to four times normal (1010 ft³/min) to show uneven cooling of roof surface

This first roof to be fitted with a curtain was taken off after 8 weeks and 114 casts, compared with an average of 8·3 weeks and 113 casts for the previous seven roofs on this furnace.

In the second trial an attempt was made to obtain more even velocity distribution by using a wedge-shaped gap (illustrated later) into which the individual jets were blown. The exit from this gap consisted of a $\frac{1}{2}$-in. slot between the roof and the top of the modified backwall, while an inspiration gap (*see* Part I) was left on the outside wall. Initially this was 1 in. wide but closed up later to only $\frac{1}{8}$ in. Although the air volumes used were reduced to 420 ft³/min and after only a few days to 290 ft³/min, corresponding to velocities of 19 and 13 ft/s at the exit from the slot, this curtain appeared to be more effective, giving a roof life of 10 weeks and 129 casts.

In the third trial, the $\frac{1}{2}$-in. exit slot was increased to 1 in., while the inspiration gap, which started at 1 in., varied between this dimension and $\frac{1}{2}$ in. throughout the campaign. The air flows varied from 290 to 230 ft³/min, giving average exit slot velocities of $6\frac{1}{2}$–5 ft/s. This roof gave a relatively excellent life of 13 weeks and 181 casts.

The arrangement used in the fourth installation was essentially similar to that used in the previous run. Figure 35 shows the designed cross-section, from which it will be seen that the air was brought into the gap behind the slot by means of a hollow brick, while the base of the slot was paved with chrome-magnesite brick resting on the backwall. As will be seen from Fig. 36, which was taken after 6 weeks' (75 casts) operation, the slot soon became rather irregular, cutting out in certain areas and being blocked in others by stalactites dripping from the roof. Incidentally this photograph, for which the air flow was raised to 1010 ft³/min, shows the cooling of the roof to be rather patchy, presumably owing to localized differences in flow rate. The condition of this particular installation at the end of the campaign is illustrated by Fig. 37, which shows a section through the roof at the backwall side at a point 2 ft 6 in. inside the curtain section. The first four courses adjacent to the skewback are virtually untouched, and even in the fifth, sixth, seventh, and eighth courses wear is relatively small compared with that anticipated where no moving air curtain is employed. The sloping base of the slot is still in existence, at least in the area shown, but several of the skewback bricks are badly cracked. Subsequent tests suggest that this may have been due to the rapid cooling that occurs if the furnace is shut off but the air curtain fan is left on.

Fig. 37—Section through fourth moving air curtain installation at end of campaign, at 2 ft 6 in. inside the protected area

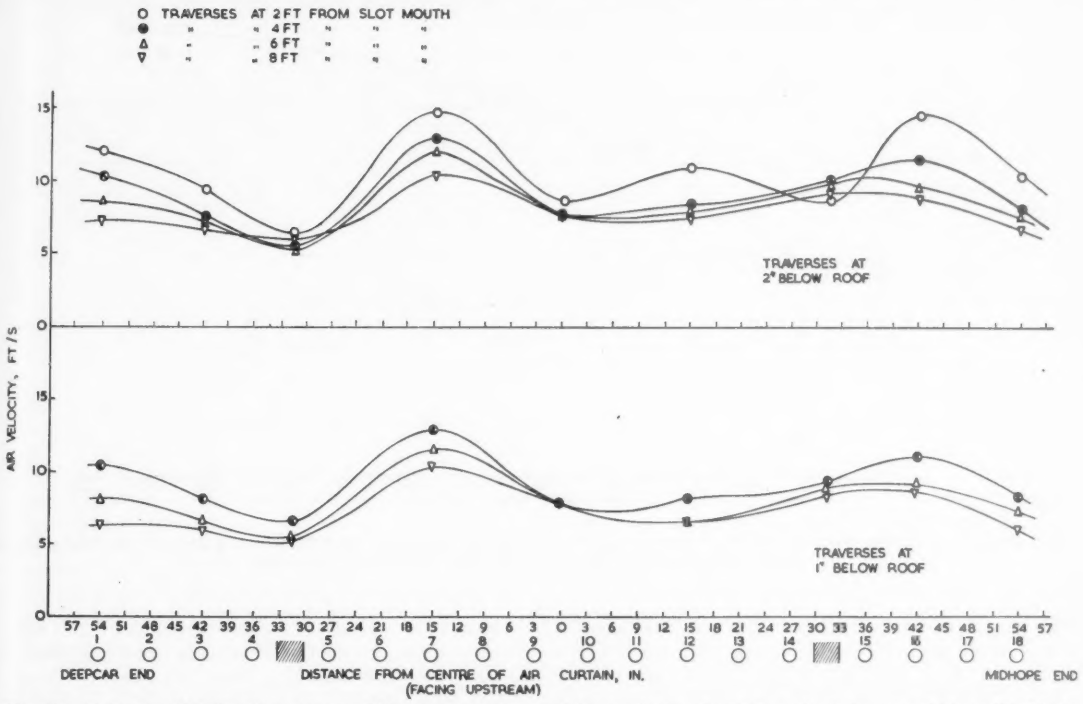
O TRAVERSES AT 2 FT FROM SLOT MOUTH
● " " 4 FT " " "
Δ " " 6 FT " " "
▽ " " 8 FT " " "
TRAVERSES AT 2" BELOW ROOF
TRAVERSES AT 1" BELOW ROOF
AIR VELOCITY, FT/S
DEEPCAR END
DISTANCE FROM CENTRE OF AIR CURTAIN, IN. (FACING UPSTREAM)
MIDHOPE END

Fig. 38—Velocity distribution across fifth moving air curtain as determined in actual furnace before flashing, with total air flow of 930 ft³/min.

An attempt was made with this roof to determine more precisely the effect on centre roof temperature of turning on the air curtain. Even with flows of 1000 ft³/min the drop appeared to be only of the order of 10° C.

The actual life of this roof was only 7 weeks (89 casts), but it was reported at the time that it had been taken off for shop programming and that it would probably have lasted at least another 5 weeks. Examination of the regions just within and just outside the curtain suggested that there had been appreciable protective action. Indeed on either side of the air curtain the guttering extended approximately 9 in. nearer to the backwall than in the protected area.

The fifth moving air curtain installation was essentially similar to the fourth, but a number of minor changes were made with a view to reducing operating difficulties. Thus the slot height was increased from 1 in. to 1½ in., to facilitate a more rugged construction and one less likely to be modified by roof movement. A parallel throat about 2½ in. long was provided at the slot outlet to improve the discharge conditions, and brick props were inserted in the air inspiration gap over the joints between the jet bricks to prevent blockage of it and possibly of the jets themselves by

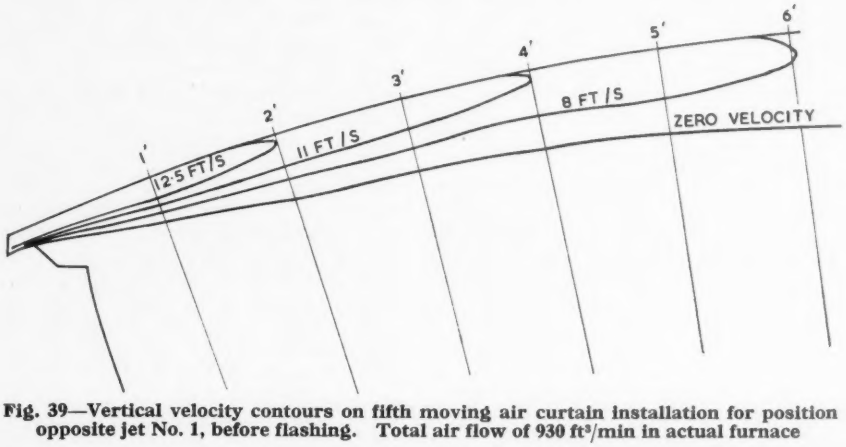

Fig. 39—Vertical velocity contours on fifth moving air curtain installation for position opposite jet No. 1, before flashing. Total air flow of 930 ft³/min in actual furnace

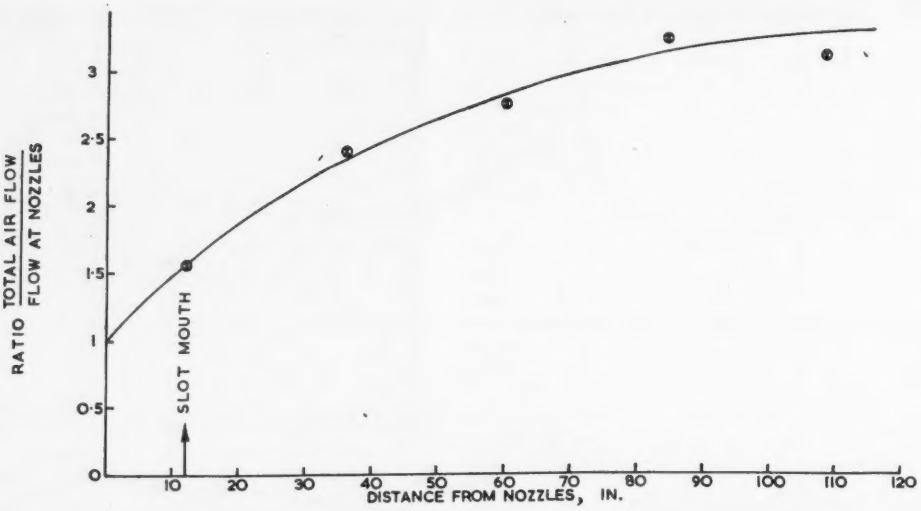

Fig. 40—Relationship between total air flow and distance from discharge, on fifth moving air curtain installation Cold test on actual furnace, with total air flow 930 ft³/min

fractured skewback bricks. This necessitated an increase in the air inspiration gap from 1 to 1½ in. to give the same total area of gap as in the previous design. Two props were also inserted in the mixing chamber, behind the slot, to support the roof at these points. These split the curtain into three sections: a group of 10 jets with two groups of 4 on either side. In addition the jet brick angle was made rather steeper and the diameter of the nozzle increased from 1 to 1½ in. The air flow was raised to 420–450 ft³/min, giving a calculated velocity along the length of the slot of 6–7 ft/s. The actual velocity, as determined by traverses in the actual furnace prior to operation, showed considerable irregularity close to the slot mouth but surprising uniformity 2 ft or more away. Figure 38 shows the data obtained at levels of 1 and 2 in. below the roof surface, from which it will be seen that the cold air stream with this particular flow rate (930 ft³/min) was of the order of 10 ft/s. The undulations observed are, of course, the result of introducing the air through a finite series of nozzles and are far more marked in regions close to the slot mouth.

A surprising and gratifying feature of these tests was the slow rate of expansion of the air sheet. Whereas it has been shown that a free jet expands at, say, an angle of 20° and one over a plane surface at about half this amount, the effective expansion in the present installation was only 2°, the tendency to expand being at least partially offset by the curvature of the roof. This only applies, however, to the region opposite the jets, the expansion being appreciably greater in the intermediate regions. Vertical velocity traverses were also carried out and are shown for the region opposite No. 1 jet, in Fig. 39. With a flow of 930 ft³/min, velocities in the cold of up to 8 ft/s or more were maintained for a distance of 6 ft from the skewback. An estimation was also made of the entrainment which occurs, the results being plotted in Fig. 40. This shows the total air flow at a given point as a function of the flow from the nozzles for various distances from the nozzle mouth. The entrainment values are considerably lower than were obtained with unrestricted jets in the laboratory, presumably owing to the intermixing of jets behind the slot.

Attempts were made to visualize the flow by means of smoke and ' artificial snow,' i.e. vaporized metaldehyde. No photographic records were obtained but visual examination showed that rapid entrainment was limited to positions close to the slot mouth and that further out movement of tracer particles only became marked when they rose to the high-velocity regions indicated by the pitot-tube traverse.

On three occasions during the campaign (viz. the 19th, 47th, and 132nd casts) measurements were made of the air flow as a function of pressure on the manifold. These readings suggested that pressure drop through the slot was fairly well maintained for most of the campaign. Photographs taken of the roof after the 19th cast suggested good air distribution, but substantial irregularities were observed after 132 casts. The final life of this roof was 12 weeks (162 casts) and the general conclusion was that appreciable protection had occurred.

The arrangement on the sixth trial was similar to that on the fifth, but on the seventh the curtain was extended to approximately 15 ft instead of the 9 ft used previously. Since it had been suggested that the blowing rates were excessive, and possibly caused transfer of the wear to the front section of the roof, the flow velocity at the exit from the slot was reduced to 5–5½ ft/s, though owing to the greater length the total flow had to be increased to 550–610 ft³/min. This roof survived 12 weeks, during which 161 casts were made. Examination at the end showed not so much the effect of the curtain as the quite outstanding protection accorded by the Silcrete (super-duty silica) strips on the back of the roof adjacent to the back and front walls. In view of this it was recommended that

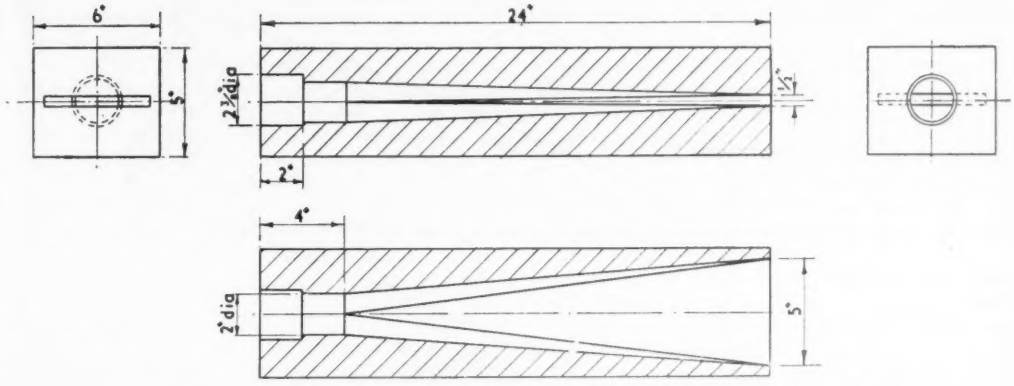

Fig. 41—Details of flared jet brick used in ninth moving air curtain installation

future trials be done on a roof of one quality only so that the influence of the curtain could be more readily distinguished.

On the next campaign, the eighth, a short life of only 6 weeks (73 casts) was obtained, the furnace again having to be taken off prematurely to fit in with the shop programme.

Use of Slotted Jet Bricks

In most of the previous trials the air curtain entered the furnace through a slot formed between the top of the backwall and the roof surface. It was felt that the installation of moving air curtains would be greatly simplified and more precise control obtained if a series of slotted bricks were used to form a virtually continuous sheet of air. Figure 41 shows the actual design of slotted brick used, the development of which has already been described in Part I. The final orifice was 5 in. × ½ in. and the adjacent slots were separated by only 1 in. of brickwork. The location of these bricks in relation to the backwall and roof is illustrated by Fig. 42, which shows that the flow is essentially tangential to the roof, the top surface of the slotted brick being only 1 in. below it and the axis of the slot 3½ in. below the roof surface. The last few courses in the backwall have been laid to give an essentially vertical section, which laboratory tests suggested might assist in reducing the amount of work to be done by the moving air curtain in turning the droplets away from the roof. Observation of the furnace during the campaign showed, however, that this vertical portion did not remain in position for very long.

Before the furnace was put into operation a careful study was made of the flow under cold conditions, tests being made not only of velocity distribution but also of deposition of aluminium introduced into the stream of air passed up the backwall. The velocity measurements, which were carried out with a pitot-static tube and curved-tube manometer, showed velocity distributions similar to those obtained in the corresponding laboratory tests. The average velocity at the exit from the slot with a total air flow of 840 ft³/min (approximately 10% of the combustion air) was 33 ft/s, but the values measured varied from 22 to 42 ft/s. Incidentally, vertical velocity contours again showed a marked tendency of the air curtain to rise towards the roof, the velocities in contact with it being to the order of 10 ft/s for the first 2 ft and 7½ ft/s for the next 2 ft.

In protection efficiency tests made on this furnace before 'flashing' the air flow up the backwall was provided by a low-capacity fan and a hollow Perspex tube with ½-in. dia. holes drilled at intervals along it to give a vertical velocity of 12 ft/s at 1 in. below the top of the wall. The aluminium powder charged was of the 30–60 B.S. mesh type. The actual efficiencies were again similar to those obtained in the laboratory, being of the order of 30% immediately above the backwall, 92% at 6 in. from this point, and 99% at 12 in. from it.

Inspection of the roof at intervals during the furnace campaign showed quite substantial deterioration of the jet bricks, the slots appearing to widen and in certain cases merge into one another. Pressure readings taken across the flexible connecting pipes suggested, however, that most of the jets remained in action.

Examination of the roof at the end of the campaign showed that the first ten courses from the skewback had worn less in the region inside the curtain than outside it, but that the wear in the next eight courses was somewhat greater where the curtain was operating. This is presumably because the curtain tends to blow the fluxes away from the part immediately above the backwall but deposit a rather larger amount furtherout. The silica jet bricks themselves were found to be badly cracked, though it was not possible to say how much side leakage had occurred. Many of them also were obstructed by stalactites dripping from the roof above.

The actual life obtained with this installation was again 12 weeks, but during this period 177 casts were made. The final cause of failure was, however, still that originally experienced, viz. excessive guttering in the region adjacent to the backwall.

Following these initial trials, moving air curtains have continued to be used on *K* furnace at S. Fox and Co., Ltd. The subsequent trials have included tests on horizontally placed bricks. Little progress has, however, been made since the last arrangement described above, in which 30 slotted bricks were placed tangentially to the roof.

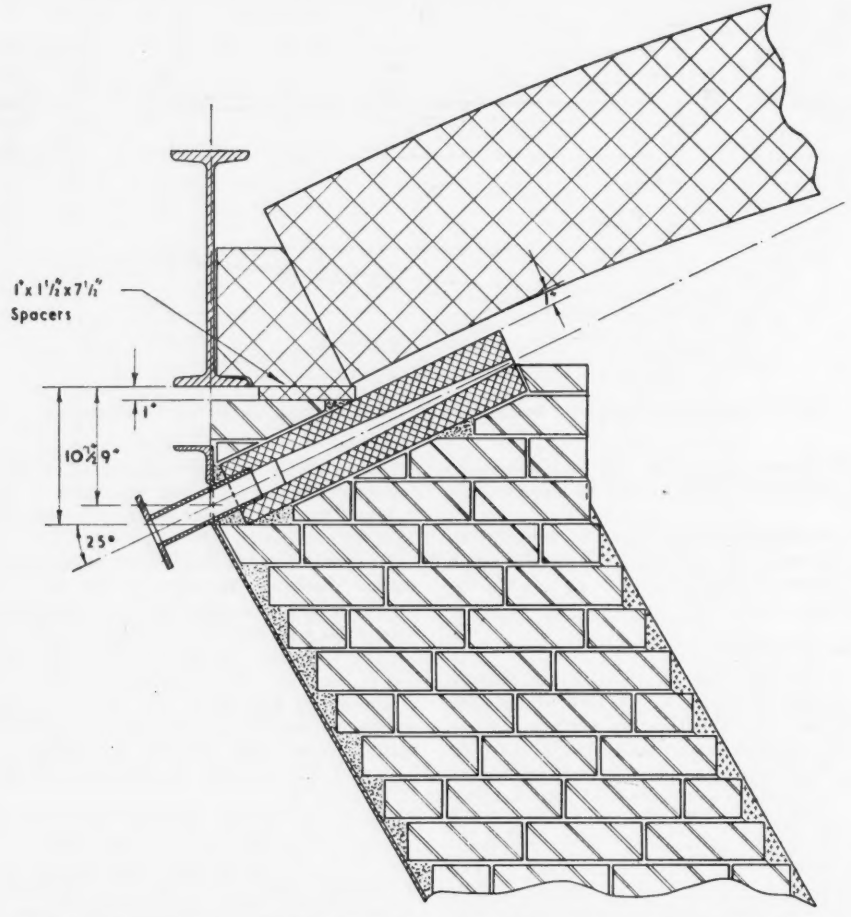

Fig. 42—Arrangement of ninth moving air curtain installation showing use of jet bricks with vertical top backwall

Iron Oxide Deposition Tests

Since it had been found in tests at Appleby-Frodingham and Steel Peech and Tozer that very interesting information on factors controlling roof wear could be obtained by the use of alumina probes inserted through holes in the roof, trials of this type were carried out on the Fox furnace, using 12 sampling points: 6 along the centreline of the jet bricks and 6 in between. The distance of the test points from the backwall were 6 in., 2 ft, and 4 ft, respectively. A considerable number of tests were carried out (in this particular case on a furnace fitted with a horizontal curtain) but negligible differences were found in the rate of iron oxide deposited with and without the moving air curtain. It would appear that the inability of this particular (horizontal) arrangement to protect the roof was due to the fact that, when the air stream was turned on, the amount of additional fluxes drawn towards the roof offset any flux protection afforded by the curtain itself.

Two incidental results of this work were, however, very interesting, viz. an appreciable decrease in the rate of deposition of iron oxide as the distance from the backwall increased, and more markedly an increase in the amount of iron deposited at a given distance from the skewback as the exit end of the furnace was approached. On the end from which the flame entered the deposit rate was less than one-third of that found at a distance of 3 ft towards the exit end from the centre-line of the furnace. This confirms the deduction from flow-pattern studies that most of the damage on silica roofs is done by deposition of iron oxide on the exit end of the furnace. Examination of the alumina probes with respect to the location of blackening enabled the flow pattern in the roof of this particular installation to be studied. This showed that, as in model studies, there was marked recirculation towards the end from which the flame entered the furnace, even when a moving air curtain was in operation.

Tilting Furnace Trials

The results obtained in moving air curtain trials on a large tilting furnace will be reported elsewhere,[6] and it need only be stated here that the use of such curtains in limited areas at the exit end of such

furnaces has enabled the iron oxide pickup, as judged by alumina probes, to be reduced to about one-third and have afforded sufficient protection to the silica brickwork in a position of severe wear to enable a furnace to complete its campaign without the intermediate roof repairs that would otherwise have been necessary. Where, as in this furnace, the wear is extremely localized the use of moving air curtains no longer suffers from the limitation of air volume, and it is possible to maintain quite high velocities with only, say, 1% of the air required for combustion.

SUMMARY AND CONCLUSIONS

(1) Repeated observations suggest that positions in open-hearth furnace roofs where wear is excessive are generally those in which high rates of deposition of iron oxide are coupled with high temperatures and sometimes reducing atmospheres.

(2) The location of these areas is consistent with the iron oxide being brought from bath level to the particular area by the flame gases in a manner predictable from flow-pattern studies.

(3) A novel furnace has been suggested in which the air enters from the opposite end to the fuel and in such a way as to separate the refractory surface from the flux-laden furnace gases by a moving layer of relatively clean air.

(4) A hot model built on this principle behaved quite satisfactorily until tested with irregular roof or hearth contours, when the flow pattern was observed to change radically, leading to completely unstable combustion conditions.

(5) The alternative idea of a moving air curtain to protect limited areas of the roof surface was therefore developed, the main objectives being to:

(*a*) Lower the concentration of fluxes
(*b*) Lower the roof temperature
(*c*) Maintain an oxidizing atmosphere

in areas where wear was normally excessive.

(6) Extensive background data have been provided by tests on free jets and jets parallel to or impinging on plane surfaces. Single jets parallel to surfaces are shown to protect limited areas in line with the jet axis and show a characteristic velocity distribution both in the surface and in a plane perpendicular to it.

(7) Inclination of the jet to the surface causes it to ' splash,' giving a somewhat wider coverage.

(8) Still better coverage was obtained by the use of a slot having its long axis parallel to the plane surface. Here again inclination to the surface of the jet axis gave broadening of the pattern.

(9) Studies of multiple jets, emerging from a series of circular and slot-shaped apertures arranged parallel to the surface to be protected, gave similar results, but indicated the presence of unprotected areas between the jets and intensive deposition of droplets at the jet edges when the atmosphere above these jets was loaded with droplets by means of a ' scent spray ' atomizer.

(10) Given a continuous slot (the laboratory unit was 21 in. $\times$ $\frac{1}{4}$ in.), much more even coverage is obtained, the undulating velocity profiles characteristic of multiple jets being virtually eliminated.

(11) The difficulties of building a continuous slot even $\frac{1}{2}$ in. wide between, say, the backwall and roof, were obviated by the development of a special flared jet brick, the aperture in which changes from a round hole at the back, where the air is introduced, to a 5 in. $\times$ $\frac{1}{2}$ in. slot at the front.

(12) Where the earlier method of introducing the air by means of a row of jets at the back of a triangular cavity between the roof and the backwall is used, considerable advantage is obtained by leaving an inspiration gap on the external surface.

(13) A full-size roof was built in steel with a sloping backwall to study the impact on the roof of dust-laden gases passing up the wall and the effect of various methods of protection. In the absence of precise operating data the air stream in the laboratory test was maintained at 12 ft/s, compared with initial curtain velocities of the order of 5–100 ft/s. The flow both of aluminium particles (30–60 mesh) and of paraffin smoke (to represent coarse and fine iron oxide droplets) was visualized by means of intense slit illumination. These tests showed not only that most of the coarse particles, though deviated by the moving air curtain, nevertheless penetrated it but also that fine fume was taken through the curtain within a foot or two of the backwall by turbulent diffusion. A quantitative technique, in which sticky papers on the undersurface of the roof were used to trap coarse particles, was used to give protection efficiency values.

(14) Numerous other methods of protection have been tried out in the laboratory; it was shown, for example, that building the backwall vertical at the top reduces the work to be done by the moving air curtain and that fairly good protection can be obtained with horizontal as distinct from tangential air streams. Other ideas tested were a perforated roof, jets pointed down the backwall, diagonal jets, twin curtains, and large-volume, low-velocity curtains.

(15) Numerous trials have been made of moving air curtains on a cold-charged open-hearth furnace, the types varying from plain 1-in. orifices at 6-in. centres to essentially continuous slots formed by a gap between the top of the backwall and the roof, or by means of flared jet bricks. Tests made in the cold on the working furnace leave little doubt that a relatively uniform moving air curtain of the desired type was established. The benefits obtained by the use of such curtains, although considered appreciable by the operators, are quite modest, and further development would be needed to justify any wide application.

The cooling effect on the roof surface was found to amount to less than 10° C at the centre but was substantially greater nearer the backwall. Alumina probe tests made with a horizontal curtain showed that the amount of iron oxide arriving at the roof was little affected by the curtain, presumably because the fast-moving sheet of air increased the amount of fume drawn up from bath level. The tests also confirmed that deposition was greatest near the backwall and tended to increase along this section of the roof as the exit end was approached.

(16) Moving air curtain trials on a tilting furnace, using larger air velocities over a more limited area, enabled substantial protection to be afforded in areas of severe attack, while alumina probe tests showed a corresponding reduction in the rate of arrival of iron oxide.

Acknowledgments

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The Solubility of Nitrogen and Formation of Silicon Nitride in Iron–Silicon Alloys

By E. T. Turkdogan and S. Ignatowicz

SYNOPSIS

Iron–silicon alloys containing 0·90%, 1·26%, and 2·83% silicon have been equilibrated with ammonia–hydrogen or nitrogen–hydrogen mixtures at various temperatures. The solubility of nitrogen in iron, in equilibrium with a nitride phase, is reduced appreciably by the formation of a silicon nitride. The inclusions in the nitrided alloys have been extracted and analysis shows that they consist of silicon nitride and silica; the latter forms during the extraction operation from the silicon in solid solution. 1366

THE DELETERIOUS EFFECTS of nitrogen on the electromagnetic properties of iron–silicon transformer metals are now well established facts. It is only recently, however, that some work has been carried out on the chemistry of nitrogen in steel. Beeghly[1, 2] has devised a method of separating nitrides, i.e. aluminium, vanadium, and silicon nitrides, from steel, and investigated the effects of heat-treatment time and temperature on the amount of the nitride separated by an ester–halogen solution. Leslie, Carroll, and Fisher[3] separated silicon nitride with an ester–halogen solution from nitrided steels containing 0·58%, 1·21%, and 3·20% silicon. They examined the X-ray diffraction pattern and the pattern obtained by transmission electron diffraction from the separated nitride, and they claim that this nitride is Si_3N_4 and has an orthorhombic structure with the following lattice parameters: $a = 13{\cdot}38$ Å, $b = 8{\cdot}60$ Å, and $c = 7{\cdot}74$ Å. Corney and Turkdogan[4] measured the solubility of nitrogen in pure iron and in 2·83% silicon–iron alloy under 1 atm of nitrogen. The results indicate that silicon lowers the nitrogen solubility in iron, and that at or below 705° C a nitride forms in this alloy in equilibrium with nitrogen at one atm. Leak, Thomas, and Leak[5] have measured the diffusion and solubility of nitrogen in 2·83% silicon–iron alloy by the internal friction method. Fast and Verrijp[6] measured, by the internal friction method, the solubilities of nitrogen in α-iron in equilibrium with 'Fe_8N,' Fe_4N, and N_2 at 1 atm pressure.

The above-mentioned data throw very little light on the thermodynamics of silicon nitride(s) in iron–silicon alloys; keeping this point in view the present work was undertaken.

EXPERIMENTAL

The apparatus and the experimental procedure employed in this work were practically the same as those described by Corney and Turkdogan[4]: namely, the iron–silicon alloys were equilibrated, at different

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temperatures, with ammonia–hydrogen or nitrogen–hydrogen mixtures, and the samples were analysed for nitrogen by a micro Kjeldahl method.

Two of the iron–silicon alloys used in this investigation were manufactured by Johnson Matthey and Co., Ltd., and were supplied in the form of a ribbon 0·002 in. thick and 1·5 in. wide; the alloys contained 0·90% and 1·26% silicon. The third alloy, containing 2·83% silicon, was an N.P.L. material rolled down to a thickness of about 0·005 in. The results of chemical and spectrographic analyses of the alloys are shown in Table I.

In experiments where the total nitrogen in iron was less than 0·01%, the samples were de-nitrided in oxygen-free, dried hydrogen for two or three days at 500° or 600° C, depending on the subsequent nitriding temperature. After this hydrogen treatment the remaining nitrogen was not greater than 0·0003%, which is within the limit of uncertainty of the analysis.

Although the previous work indicated that 24 h was long enough to attain equilibrium for the solution of nitrogen in iron, the formation of a second phase on the surface of the sample might prolong the time necessary for the formation of this nitride in the bulk of the material. It was, therefore, considered advisable to extend the time of reaction to as long as five days.

The samples were analysed for nitrogen by a modified micro Kjeldahl method as described by Beeghly.[2] A number of samples were also analysed using the sulphuric acid fuming method and concordant results were obtained by both. The only difference between these two methods was that the dissolution of the sample in 1 : 1 hydrochloric acid, containing a few drops of hydrofluoric acid and hydrogen peroxide, was found to be quicker than using sulphuric acid. A large number of samples analysed by either method indicated that the reproducibility of the nitrogen analysis was within ± 0·0005%.

In every experiment the outgoing gas was analysed for ammonia by collecting a definite volume of the gas and passing it through a standard hydrochloric acid solution in which the ammonia was absorbed; the excess hydrochloric acid was then titrated with a standard solution of borax. At temperatures of 500° and 600° C, the composition of the outgoing gas was within ± 0·5% of the incoming gas, indicating no measurable decomposition of ammonia at these temperatures.

Table I

ANALYSIS OF THE ALLOYS

Percentage by Weight of Impurities

Impurity	0·90% Si–Fe	1·26% Si–Fe	2·83% Si–Fe
C	<0·01	<0·01	0·002
N	0·013	0·012	0·001
O	...	...	0·0005
Al	<0·01	<0·01	0·003
P	<0·01	<0·01	0·003
S	<0·01	<0·01	0·004
Ti	<0·005	<0·005	<0·005
V	<0·01	<0·01	<0·01
Cr	<0·01	<0·01	0·001
Mn	<0·01	<0·01	0·004
Co	<0·01	<0·01	<0·01
Ni	<0·01	<0·01	0·010
Cu	<0·01	0·22	0·006
Mo	<0·01	<0·01	<0·01
W	<0·05	<0·05	<0·01

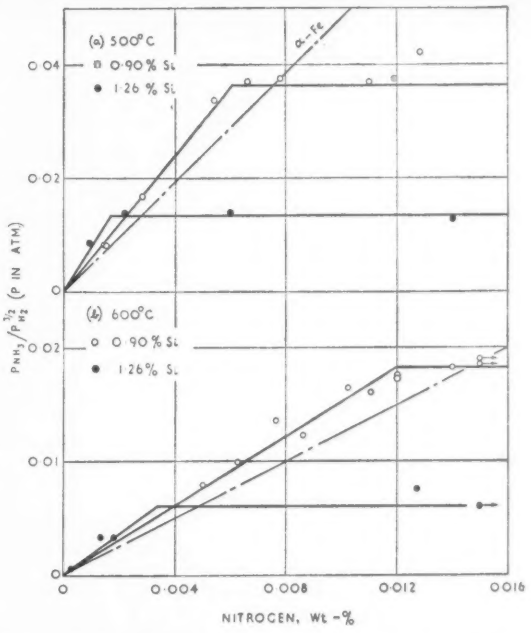

Fig. 1—Solubility of nitrogen and formation of a silicon nitride in α-Fe–Si alloys at 500° and 600° C

RESULTS

Nitrogen in α-Iron–Silicon Alloys

The results of the experiments at 500° and 600° C with 0·90% and 1·26% silicon–iron alloys are given in Fig. 1, where the gas ratio $\frac{P_{NH_3}}{(P_{H_2})^{\frac{3}{2}}}$ (p in atm) is plotted against the weight per cent of nitrogen in the alloy. It is interesting to note that at low nitrogen potentials, i.e. below those required to form a silicon nitride, the solubility of nitrogen in α-iron is reduced by silicon.

Sudden increases in the nitrogen content of the samples indicate the formation of a silicon nitride, because at these very low nitrogen potentials iron nitride Fe_4N does not form. Further consideration will be given to these nitrides later in the paper.

As indicated by the curves in Fig. 1*b*, at silicon concentrations much higher than 1·3% a nitride phase forms at very low nitrogen partial pressures, and these could not be measured accurately by using ammonia–hydrogen mixtures. The alloy containing 2·83% silicon was, therefore, equilibrated with nitrogen–hydrogen mixtures at 600° C, and the results are plotted in Fig. 2 in a semi-logarithmic form. There is a clear indication that at or above 0·75 atm of nitrogen a nitride phase forms. These results compare favourably with those of Corney and Turkdogan,[4] who showed that a nitride is formed at and below

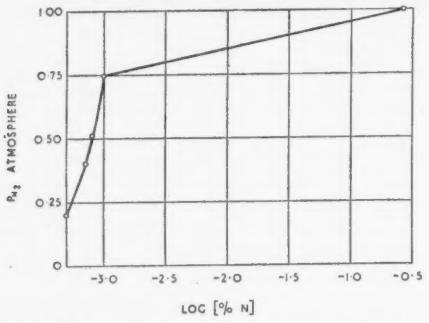

Fig. 2—Solubility of nitrogen in 2·83% Si–Fe alloy at 600° C

705° C, when this alloy is equilibrated with nitrogen at one atm. It therefore follows that at 600° C, the critical nitrogen pressure must be below one atm, and this critical value may be taken as 0·75 atm.

Nitrogen in γ-Iron–Silicon Alloys

Since ammonia begins to decompose at temperatures above 600° C, the work within the γ-phase was limited to an atmosphere of 98% nitrogen and 2% hydrogen mixture. The latter gas was introduced first to ensure that the samples could not be oxidized, and secondly to increase the rate of solution of nitrogen in iron.[6] In these experiments, carried out within the temperature range 950–1350° C, the samples were kept in the reaction chamber for three days only, as this time of reaction was proved to be sufficient to attain equilibrium. In Fig. 3, the logarithm of the weight per cent of nitrogen is plotted against the reciprocal of the absolute temperature. For reasons to be discussed later, this plot for a fixed pressure of nitrogen should give a straight line. The top line, which is reproduced from the work of Corney and Turkdogan,[4] gives the nitrogen solubility in pure γ-iron under similar conditions. As in the α-phase, silicon lowers the nitrogen solubility in the γ-phase. The points of intersection of the solubility lines with the lines drawn downwards are the transformation points which are taken from the results of Rickett and Fick.[7] The point for 1·26% silicon for 990° C lies well below the others, indicating that at this temperature this alloy must have been within the $\alpha + \gamma$ two-phase region. This is in agreement with the data on γ loop in iron–silicon alloys.[7]

Darken, Smith, and Filer[8] also showed that silicon lowers the nitrogen solubility in γ-iron. Their results, however, are not shown in Fig. 3 because the points for 0·20% and 0·58% silicon are scattered more than those of the authors.

Formation of Silicon Nitride

Although the results in Fig. 1 give the values of the gas ratio $\frac{p_{NH_3}}{(p_{H_2})^{\frac{3}{2}}}$, and the nitrogen in solution in equilibrium with a nitride phase (presumably a silicon nitride), they provide no information on the nature of this second phase. Keeping this point in view, a series of experiments was carried out at 600° C at much higher nitrogen pressures. When the gas ratio is raised above the critical value for a given iron–silicon alloy, a silicon nitride will form, until the silicon left in solid solution is in equilibrium with this silicon nitride and the gaseous phase. If further nitride is to be formed in the same alloy, then the partial pressure of the nitrogen must be increased. Although along each curve in Fig. 4 the total silicon remains constant, the silicon in the solid solution decreases with increasing nitrogen pressure. At the initial stages of the nitride formation, the difference between the total silicon and that in solid solution will be very small, and for this reason the lines in Figs. 1*a* and 1*b* are drawn horizontal at the critical values.

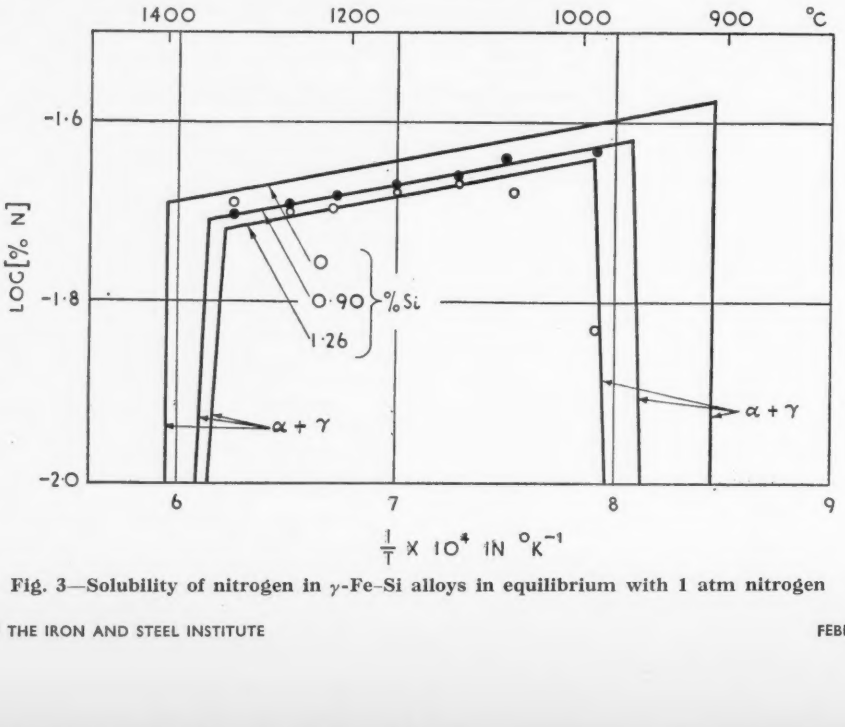

Fig. 3—Solubility of nitrogen in γ-Fe–Si alloys in equilibrium with 1 atm nitrogen

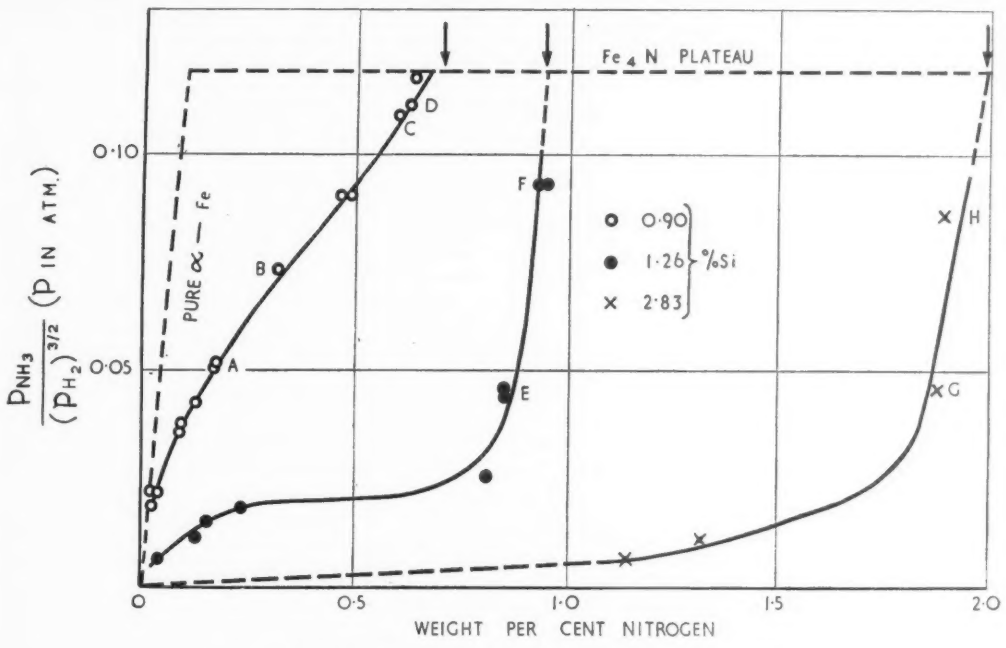

Fig. 4—Formation of silicon nitride in Fe–Si alloys at 600° C

In all the experiments recorded in Fig. 4, at various ammonia/hydrogen ratios, the time of reaction was two weeks at 600° ± 1° C. The consistency of the results indicates the attainment of equilibrium during nitride formation.

The nitrides in a number of samples (marked in Fig. 4) have been separated by the method recommended by Beeghly[1]: namely, a weighed sample was dissolved in bromine (8·94 g bromine/g of steel) containing some methyl acetate (2 ml/g of steel). When the initial vigorous reaction subsided, more methyl acetate was added (13 ml/g of steel) and the container was heated slowly until the sample was completely dissolved. When cold, the solution was filtered through a sintered crucible (previously weighed), washed well with methyl acetate, and dried in air at 105° C, and weighed. In a few cases the residue was dried at 350° C for about 12 h and no change in weight was observed. The data on the extracted material are given in Table II and the following comments may be made on these results.

If all the silicon and nitrogen in the original sample (*1*) were retained in the residue, then the latter should contain 11·7 mg silicon and 0·2 mg nitrogen. Assuming that 0·2 mg of nitrogen combined with 0·3 mg of silicon to form Si_3N_4, then 11·4 mg of silicon would be in the form of silica amounting to 24·4 mg; the sum of this amount with 0·5 mg of Si_3N_4 gives 24·9 mg, which compares very well with the amount of residue actually extracted. This agreement is fortuitous and throws no light on the form of silicon nitride, but it indicates that all of the silicon in

Table II

EXTRACTION OF INCLUSIONS FROM NITRIDED SILICON-IRON

No.	Si, %	N, %	Sample Weight, g	Residue Weight, mg	Calculated			Analysed		
					Si, mg	N, mg	$\frac{Si}{N}$	Si, mg	N, mg	$\frac{Si}{N}$
1	0·90	0·013	1·3038	24·8	11·7	0·2	2·00	...	...	...
A	0·90	0·180	0·8840	12·8	8·0	1·6	3·25	...	...	...
B	0·90	0·316	0·4396	7·0	3·9	1·4	1·72	...	...	...
B2	0·90	0·316	0·5220	7·4	4·7	1·6	2·31	3·7	1·4	1·28
C	0·90	0·600	0·5469	8·4	4·9	3·3	1·48	4·2	...	...
D	0·90	0·625	0·9515	15·4	8·6	5·9	1·39	7·3	4·4	0·93
E	1·26	0·85	0·7906	16·8	10·0	6·7	1·48	...	5·9	...
F	1·26	0·94	0·8030	17·7	10·1	7·5	1·33	8·6	6·3	0·92
G	2·83	1·88	0·8314	39·4	21·7	15·6	1·25	17·5	15·6	0·72
H	2·83	1·90	0·7680	37·3	22·7	14·6	1·56	17·4	14·2	0·82

Table III
CALCULATED DATA

Temp., °C	[% Si]	[% N]	$\frac{P_{NH_3}}{(P_{H_2})^{\frac{3}{2}}}$	γ_N^{Si}
500	0·90	0·0060	$0·036_5$	1·29
500	1·26	0·0017	$0·013_2$	1·65
600	0·90	0·0120	$0·018_2$	1·27
600	1·26	0·0034	$0·006_0$	1·48
600	2·83	(0·0003)	0·75 atm N_2	...
705	2·83	0·0009	1·0 atm N_2	1·69

solution in steel comes out as silica during extraction. In fact, on treating the sample with hydrofluoric acid, all the residue was lost on evaporation. When the silicon alloy is nitrided until equilibrium is established, the system will consist of silicon nitride and silicon in solid solution. On extraction most of this silicon will separate as silica along with the silicon nitride. An attempt may now be made to calculate the amount of silicon as silicon nitride and silica from (*a*) the total silicon and nitrogen contents of the alloy, (*b*) the weight of the sample used for extraction, and (*c*) the amount of the residue extracted. For example, the amounts of silicon and nitrogen in 0·5220 g of sample B2 are 4·7 and 1·6 mg respectively; since the amount of residue extracted is 7·4 mg then the difference $7·4 - (4·7 + 1·6) = 1·1$ mg of oxygen. This amount of oxygen requires 1·0 mg of silicon to form silica, and therefore the amount of silicon in combination with nitrogen will be $4·7 - 1·0 = 3·7$ mg. The ratio of this silicon to the amount of nitrogen in the residue becomes $(Si)_N/N = 2·31$. This residue was also analysed for silicon and nitrogen giving 3·7 mg silicon and 1·4 mg nitrogen. Using these figures and the amount of residue, it appears that silicon $(Si)_N$, in combination with 1·4 mg nitrogen, is 1·7, making $(Si)_N/N$ ratio $1·7/1·4 = 1·28$.

A number of extracts were analysed for silicon and nitrogen, the latter analysis by the usual micro Kjeldahl method. For the determination of silicon, the extract was digested in hot concentrated nitric acid in a small platinum crucible under an infra-red reflector lamp: when dry, the residue was heated to about 1000° C in a muffle and then weighed. This residue, now assumed to be silica, was treated with hydrofluoric acid in the usual manner.

It is to be noted that in all cases the amounts of nitrogen, and particularly of silicon, analysed are somewhat lower than those calculated. This may be due to

(i) incomplete decomposition of the extract in strong acid solution for the determinations of silicon and nitrogen
(ii) loss of some nitrogen during dissolution
(iii) dissolution of some of the silicon and nitrogen in the ester-halogen solution during the extraction operation.

Although semi-micro techniques were used in the analysis of the extracts, discrepancies between the analysed and calculated values of silicon and nitrogen in Table II make the computation of the $(Si)_N/N$ ratio (last column) unreliable. The values of $(Si)_N/N$ derived from the calculated amounts of silicon and nitrogen are believed to be more reliable; in samples *C* to *H* (almost completely nitrided) this ratio falls between 1·25 and 1·56.

In order to assist the X-ray examination of the extract, pure silicon nitrides have been prepared, and the present indications are that there are two nitrides of silicon. The nitride in equilibrium with nitrogen at 1 atm is found to be Si_3N_4. The nitride formed in the presence of excess silicon, however, gives entirely different X-ray diffraction lines, and on further heat treatment in pure nitrogen this compound can all be converted to Si_3N_4. The lower nitride was formed by heating pure silicon at 1450° C for about 30 min in an atmosphere of nitrogen. The X-ray diffraction pattern and chemical analysis showed that this substance contained unreacted silicon, Si_3N_4, and a lower nitride of silicon. Further experiments indicated that this lower nitride could be prepared almost free of Si_3N_4 by heating pure silicon at 1450° in a 10% nitrogen + 90% hydrogen mixture at 1 atm pressure. Further work is still being done on pure silicon nitrides.

The X-ray powder patterns of the extracts were obtained by using a 9-cm Debye-Scherrer powder camera and iron-filtered cobalt radiation. Even after 24 h exposure time the diffraction lines obtained were rather faint. Nevertheless, visual examination as well as measurement of the lines indicated that the diffraction pattern of the extract is in complete agreement with that of the lower nitride. In view of the evidence in Fig. 4 (discussed later), the values of $(Si)_N/N$ (calculated) in Table II, and the X-ray examination, it appears quite conclusive that the silicon nitride which is formed in iron–silicon alloys, under equilibrium conditions, is not Si_3N_4 but a lower nitride whose composition is very close to that of the higher nitride, Si_3N_4.

DISCUSSION

The following is one of the reactions studied in the present investigation:

$$\tfrac{3}{2}H_2 + [N] = NH_3 \quad \ldots\ldots(1)$$

the equilibrium ratio being

$$K' = \frac{P_{NH_3}}{(P_{H_2})^{\frac{3}{2}}} \times \frac{1}{[\%N]} \quad \ldots\ldots(2)$$

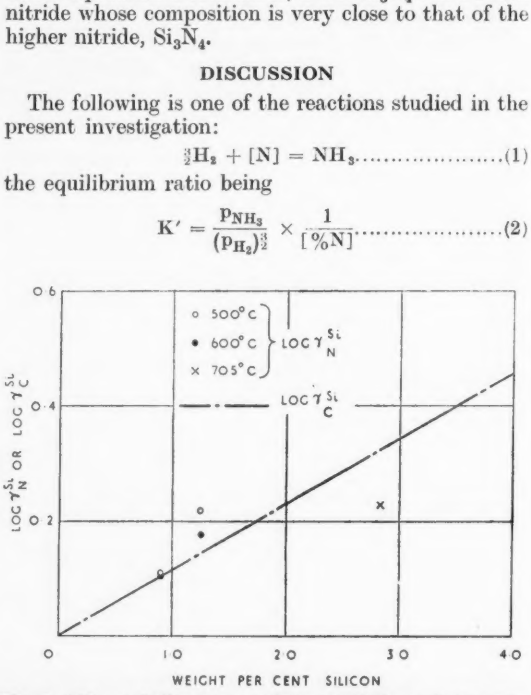

Fig. 5—Effect of silicon on activity coefficient of nitrogen in α-Fe–Si alloys

In the previous work with pure iron,[4] it was shown that the plot of $p_{NH_3}/(p_{H_2})^{\frac{3}{2}}$ against [%N] gives a straight line, indicating that the solution of nitrogen in iron obeys Sievert's law. In other words, the slopes (K) of the broken lines in Figs. 1*a* and 1*b* give the equilibrium constants of reaction (1) at 500° and 600° C. In the presence of 0·90% and 1·26% silicon, the slopes (K′) of the solubility lines increase. If it is assumed that the solution of nitrogen in iron–silicon alloys also obeys Sievert's law, then the ratio K′/K gives the effect of silicon on the activity coefficient of nitrogen, γ_N^{Si}. The values of γ_N^{Si}, calculated from the data in Fig. 1, are given in the last column of Table III. The values of [%N] and γ_N^{Si} for a 2·83% silicon alloy at 705° C are derived from a reconsideration of earlier work.[9]

In Fig. 5 the values of $\log\gamma_N^{Si}$ are plotted against the percentage of silicon. The line drawn is calculated from the data of Smith,[10] showing the effect of silicon on the activity coefficient of carbon in ferrite at 1000° C, at carbon concentrations of less than 0·05%. Since the activity coefficient factor is the ratio of the activity of X in an iron alloy to that in pure iron (X being carbon or nitrogen), the effect of temperature on this factor γ_X^{Si} will be very small and may not be observed from the equilibrium measurements. Considering the difficulties involved in the determination of the solubility of nitrogen in iron containing more than 1·0% silicon, it is reasonable to assume from the results in Fig. 5 that the effect of silicon on nitrogen activity is similar to that on carbon dissolved in α-iron. In other words, the variation of γ_N^{Si} with silicon content may be taken to be the same as that for γ_C^{Si}.

For the solution of nitrogen in γ-iron alloys, the following reaction may be considered:

$$\tfrac{1}{2}\,N_2 = [N] \qquad (3)$$

Since Sievert's law is obeyed, the equilibrium constant of this reaction at 1 atm of nitrogen is given by [%N], and the plot of log [%N] against the reciprocal of the absolute temperature is expected to be a straight line. Within the limits of the experimental errors, the lines in Fig. 3 for 0·90% and 1·26% silicon–iron alloys may be drawn parallel to that for pure γ-iron, which is reproduced from the previously

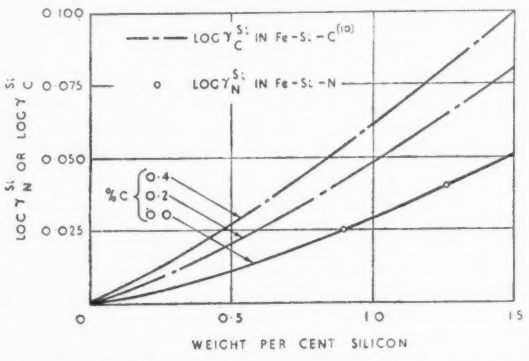

Fig. 6—Effect of silicon on activity coefficient of nitrogen in γ-Fe–Si alloys

Table IV
DISPLACEMENT OF CURVES IN FIG. 4

$\frac{p_{NH_3}}{(p_{H_2})^{\frac{3}{2}}}$	1·26–0·90		2·83–0·90		2·83–1·26	
	ΔN_1	$\frac{0·36}{\Delta N_1}$	ΔN_2	$\frac{1·93}{\Delta N_2}$	ΔN_3	$\frac{1·57}{\Delta N_3}$
0·02	0·42	0·86	1·62	1·19	1·15	1·36
0·03	0·74	0·49	1·73	1·11	0·98	1·60
0·05	0·71	0·51	1·69	1·14	0·98	1·60
0·07	0·59	0·61	1·58	1·23	0·99	1·58
0·09	0·45	0·80	1·46	1·32	1·01	1·55
0·11	0·32	1·13	1·35	1·43	1·03	1·52

published results.[4] The difference between log [%N] for pure γ-iron and that for silicon–iron, for a given temperature, gives the value of log γ_N^{Si}, which is independent of temperature, i.e. the heat of solution of nitrogen in γ-iron is not affected by small percentages of silicon.

In Fig. 6 log γ_C^{Si} is plotted against the silicon concentration from the data of Smith,[10] for alloys containing 0·2% and 0·4% carbon. The curve drawn through the points for log γ_N^{Si} (calculated from data in Fig. 3) is concordant with the extrapolation of Smith's data to zero carbon level. In other words, it is safe to assume that at very low carbon concentrations, the variation of γ_N^{Si} with silicon is the same as that for γ_C^{Si}, and independent of temperature.

From thermodynamic considerations it may be stated that for a given temperature and gas ratio $p_{NH_3}/(p_{H_2})^{\frac{3}{2}}$ the concentration of silicon in solution will be the same, irrespective of the total silicon content of the alloy and the composition of the nitride. In other words, for any curve in Fig. 4, a given gas ratio will correspond to a certain silicon concentration in solution, provided the activity of the silicon nitride is not affected by the total silicon content of the alloy. Under these conditions, the displacement of the curves in Fig. 4, measured by the difference in their nitrogen contents for the same gas ratio, should remain constant.

Calculations are given in Table IV where ΔN_1, ΔN_2, and ΔN_3 are the differences between the nitrogen contents of pairs of curves for a given ammonia/hydrogen ratio; for example, ΔN_1 represents the difference between 1·26% and 0·90% silicon alloy curves. If one particular type of silicon nitride formed along all the curves, then the ratios $0·36/\Delta N_1$, $1·93/\Delta N_2$, and $1·57/\Delta N_3$ would be the same at any nitrogen potential.

According to the data in the last column of Table IV, it may be assumed that the nitride formed in alloys containing 1·26% and 2·83% silicon has a composition close to Si_3N_4. It is reasonable to assume that, at gas ratios very close to that for the formation of Fe_4N, almost all the silicon will be converted to silicon nitride, and the total nitrogen in the alloy will consist of the nitrogen required by silicon to form a nitride, plus nitrogen in solid solution in iron (0·1% nitrogen at 600° C in equilibrium with Fe_4N). The arrows marked on the horizontal broken line in Fig. 4 correspond to complete conversion of silicon to Si_3N_4.

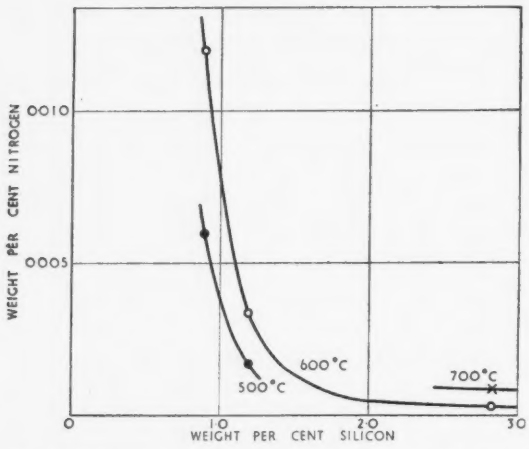

Fig. 7—Solubility of nitrogen in Fe–Si alloys in equilibrium with silicon nitride

It is interesting to note that the extrapolations of the curves to the Fe_4N plateau agree very well with the positions of the arrows.

The departure of the Si/ΔN ratios from about 1·5 in columns 3 and 5 of Table IV may result from lack of equilibrium in the nitriding experiments with 0·90% silicon alloy. Although the experimental technique was the same for all the alloys, the shape of the curve for 0·90% silicon alloy differs considerably from the other two.

The relationship important from the metallurgical point of view is that of the solubility of nitrogen in iron–silicon alloys in equilibrium with the precipitated silicon nitride. In Fig. 7, the percentage of nitrogen in solid solution is plotted against the concentration of silicon in solution, from the results in Table III. The value of 0·0003% nitrogen for 2·83% silicon at 600° C was derived by correcting nitrogen solubility[4] in pure α-iron under 1 atm to $p_{N_2} = 0{\cdot}75$ atm and by allowing for $\gamma_N^{Si} = 2{\cdot}1$ in α-phase.

The nitrogen solubility determined by Leak, Thomas and Leak[5] differs considerably from those of the authors. According to their measurements this solubility is 0·004% and 0·006% at 600° and 700° C in 2·83% silicon alloy. Their high results may be due to the formation of a silicon nitride which is not stable under the true equilibrium conditions prevailing in the present experiments.

In the present investigation, attempts have also been made to nitride a high-purity commercial 4% silicon–iron transformer metal. Before the nitriding experiment, the surface of the sample was cleaned with emery cloth and pickled in a strong acid solution, and, after careful washing and drying, it was heat-treated in pure hydrogen for three days at 600° C. After this treatment, which should have removed the surface scale, the sample was kept at 600° C for one month in a nitriding atmosphere containing 98% nitrogen and 2% hydrogen; the nitrogen content of the sample was only 0·008%. Under equilibrium conditions, however, about 1·0–1·5% of the silicon should have been nitrided, as indicated by the results in Fig. 2 on 2·83% silicon alloy. A similar experiment was made with this commercial alloy in a 10% ammonia + 90% hydrogen mixture, the time of reaction being two weeks. After this treatment, the nitrogen content of this alloy was about 0·1%. Had the equilibrium been established, almost all the silicon should have been converted to nitride, raising the nitrogen content of the alloy to about 6%. Darken, Smith and Filer[8] also experienced this difficulty of nitriding commercial iron–silicon alloys.

Another example of certain peculiarities of the commercial iron–silicon alloys is that given by Sloman[11] who found that aluminium-killed 4% silicon steel contained silicon nitride (Si_3N_4) which was acid-resistant. And yet the silicon nitride extracted from the alloys used in the present work was soluble in hot acid solutions.

CONCLUSIONS

Silicon lowers the solubility of nitrogen in α- and γ-iron, and forms a silicon nitride at nitrogen potentials much lower than those of Fe_4N.

The nitrogen in solid solution in equilibrium with a silicon nitride decreases appreciably as the concentration of silicon in solution increases. For example, at 600° C, nitrogen in solution is 0·008% in 1·0% Si–Fe, and in 3·0% Si–Fe nitrogen solubility is reduced to about 0·0002%.

For a given silicon concentration, the nitrogen in solution in equilibrium with the silicon nitride increases with temperature, and as seen from Fig. 7 this temperature effect becomes more noticeable at low silicon concentrations.

The present results suggest that the silicon nitride formed in iron–silicon alloys may not be Si_3N_4, but a lower nitride whose composition is close to that of Si_3N_4.

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The Isothermal Transformation of Lamellar Pearlites to Austenite

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SYNOPSIS

The isothermal transformation of lamellar pearlites to austenite in a plain carbon eutectoid steel at supercritical temperatures has been examined using an electrical resistance technique. The relationship between interlamellar spacing, temperature, and rate of transformation has been investigated and equations which express this relationship have been formulated. Because the transformation has not been examined fully by metallographic methods, it has not been possible to determine separately nucleation rates and growth velocities of austenite. 1219

PREVIOUS WORK

THE LITERATURE on the austenite–pearlite transformation is quite extensive but in the main concerns the breakdown of austenite. The reverse reaction has been studied to a lesser degree and, so far as the authors are aware, only a small part of previous work has been concerned with the isothermal transformation of pearlite to austenite.

Arnold and Williams[1] suggested that austenite forms by nucleation and growth. Subsequently the transformation was examined in greater detail. Portevin and Bernard[2] and Jungbluth[3] investigated the effect of initial structure, while Andrew *et al.*,[4] Lundgren,[5] and Mirken *et al.*[6] have observed that the rate of solution of residual carbide particles in austenite appears to be somewhat slower than that of the majority of the pearlite. More pertinent research concerning the mechanism and kinetics of the pearlite to austenite reaction has been carried out since 1930. Walldow,[7] Grossman,[8,9] Davenport and Bain,[10] and Bayertz[11] have established that the location of the austenite nuclei is primarily in the interfaces of the ferrite–cementite lamellæ and that the reaction does, in fact, proceed by nucleation and growth. In addition it has been observed that the structure of the parent pearlite influences the regularity in shape of the austenite phase. In the early stages of the reaction, when the austenite regions are small, they almost certainly have irregular shapes. At a later stage in the reaction they tend to become more regular, but are still not spheroidal, and ultimately the structure consists entirely of polyhedral austenite grains.

Previous work on the pearlite–austenite transformation has been reviewed by Roberts and Mehl,[12] who reached the following conclusions:

(1) The rate of formation of austenite is dependent on both the rate of nucleation and the velocity of growth.

(2) The duration of transformation decreases as the isothermal transformation temperature increases and as the pearlite interlamellar spacing decreases.

(3) The rate of nucleation and growth velocity are almost constant throughout an isothermal transformation. The austenite grain size has been calculated from the ratio of these two quantities.

The Interlamellar Spacing of Pearlite

Belaiew[13] postulated that the wide variation in the interlamellar spacing observed on a plane of polish was an apparent rather than a real effect. This variation was attributed to random orientation of the pearlite grains with respect to the polished surface, and Belaiew thought that the minimum spacing would occur when the laminations were perpendicular to the polished surface. This minimum spacing was considered to be uniform throughout each of the specimens examined because the latter had been prepared by very slow cooling from austenite, and it was also thought to be a principal and significant characteristic of the pearlite in each sample.

In the discussion on Belaiew's paper, the assumption that the interlamellar spacing remains constant for the whole volume of the pearlite (i.e. for different grains, where the thermal conditions in the A_1 interval have been the same) was questioned. However, it was generally agreed that the more uniform the heat-treatment, the more constant would be the interlamellar spacing. Rosenhain[14] suggested that the case would be proved more fully if grains were examined which had been cut in two sections at right-angles. Benedicks[15] made a similar suggestion but also argued that the variation in apparent spacing shown by a large number of pearlite grains on a single plane of polish ought to agree with a variation calculated using probability mathematics, provided that the true interlamellar spacing is constant throughout the specimen.

Green[16] attempted to correlate the mechanical properties of pearlite with interlamellar spacing, which was measured using Belaiew's method. Similar experiments have also been carried out by Gensamer, Pearsall, and Smith.[17] At a later date Mehl *et al.*[12] used Rockwell hardness values in order to differentiate between pearlites having various spacings. The kinetics of austenite formation in these specimens was then correlated with their respective hardness values.

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The authors were members of the Department of Metallurgy at the College of Science and Technology, Manchester, when this work was carried out.

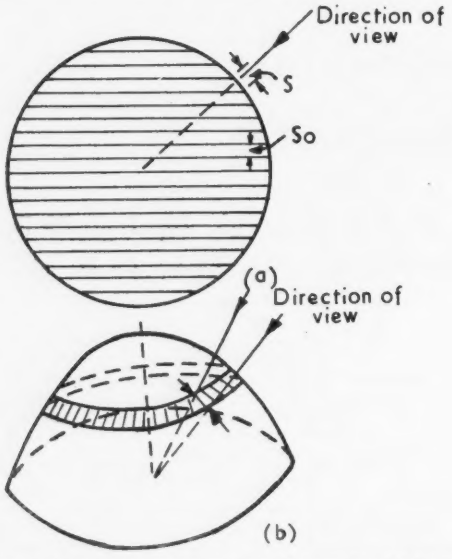


Fig. 1—Diagrams to illustrate model used by Mehl *et al.* for determining the interlamellar spacing of pearlite (S_o)

Probably the most significant contribution to the knowledge of interlamellar spacing in pearlite has been made by Mehl *et al.*[18] Pearlite prepared by the isothermal decomposition of austenite in a small specimen of (approximately) eutectoid steel was examined microscopically in such a manner that the pearlite was fully resolved. Approximately 150 photographs taken at random throughout the specimen were recorded. In each photograph, the area which included laminations whose spacings lay within certain limits was determined using a very laborious graticule method. It was concluded that the interlamellar spacing of pearlite formed isothermally is not exactly constant, but rather consists of a statistical distribution about a mean value. It is therefore more precise to speak of a mean interlamellar spacing and, further, this spacing should be significant in the applications of interlamellar data. The mean interlamellar spacing was found to be about 1·65 times the smallest observed apparent spacing and hence it is of little significance to adopt, as suggested by Belaiew, the smallest apparent spacing as the true interlamellar spacing in a given case.

The derivation of the theoretical distribution curve for apparent spacings of pearlite lamellæ on a random sectioning plane was calculated by Mehl *et al.*[18] on the following assumptions:

(1) Each pearlite colony consists of alternate parallel lamellæ of cementite and ferrite, the interlamellar spacing S_o being constant within each colony and the same for all colonies.

(2) The pearlite colonies are randomly distributed in space with respect to orientation, shape, and size.

Diagrams which represent the model used by Mehl are shown in Fig. 1. The model consists of a large sphere of parallel pearlite of interlamellar spacing S_o which may be viewed from any direction (Fig. 1*a*). If the sphere is sufficiently large, the probability that pearlite of apparent spacing S will be seen is proportional to the spherical area occupied by pearlite of this spacing, for example, as indicated by the hatching in Fig. 1*b*. (For computation, only a hemisphere need be considered.) If the above assumptions are correct, then in a random section of a sample containing many pearlite colonies, the area fraction of the polished surface occupied by pearlite of apparent spacing S should be equal to the area fraction derived from the model described above. Mehl has derived the following equation using this model:

$$S_o^2 = S^2 (1 - f_s^2) \qquad (1)$$

where S_o is the minimum interlamellar spacing, S is the apparent interlamellar spacing, and f_s is the area fraction of the plane of polish occupied by spacings lying between S_o and S.

Mehl[18] has given graphs which show f_s plotted against S/S_o according to the theoretical derivation given above and also the results of the experimental work described previously. From a comparison of these graphs the deduction has been made that the mean interlamellar spacing in pearlite is about 1·65 times greater than the minimum spacing.

This method for determining the mean interlamellar spacing experimentally is rather tedious and Mehl refers to a method developed by Pearsall.[19] The sample of steel is examined microscopically in such a manner that only a fraction of the pearlite lamellæ is resolved. The resolved areas in a number of photographs of regions selected at random throughout the specimen are measured and a mean value selected. For reasonable accuracy, however, it is probably necessary to consider at least 100 pearlite colonies. In equation (1), f_s is equivalent to the fraction of the area in which the pearlite lamellæ are not resolved. S is the minimum interlamellar spacing which can be resolved by the microscope. The resolving power of a biological microscope for a specimen critically illuminated is commonly accepted as

$$\Delta = \lambda/2NA$$

where Δ is the minimum distance resolved $= S$, λ is the wavelength of the light being used, and NA is the numerical aperture of the microscope objective.

In metallurgical microscopy, the slip in the plane-glass type of vertical illuminator impairs the resolution performance and one of the authors (C.H.) has found that the expression $\Delta = 3\lambda/4\ NA$ is a better approximation to the true resolving power. This

Table I
INTERLAMELLAR SPACING VALUES

Specimen	Unresolved Area Fraction	S, μ	S_o, μ
1	0·915	0·459	0·185
2	0·500	0·459	0·398
3	0·020	0·459	0·489
4	0·020	0·866	0·865
5	0·250	0·380	1·333

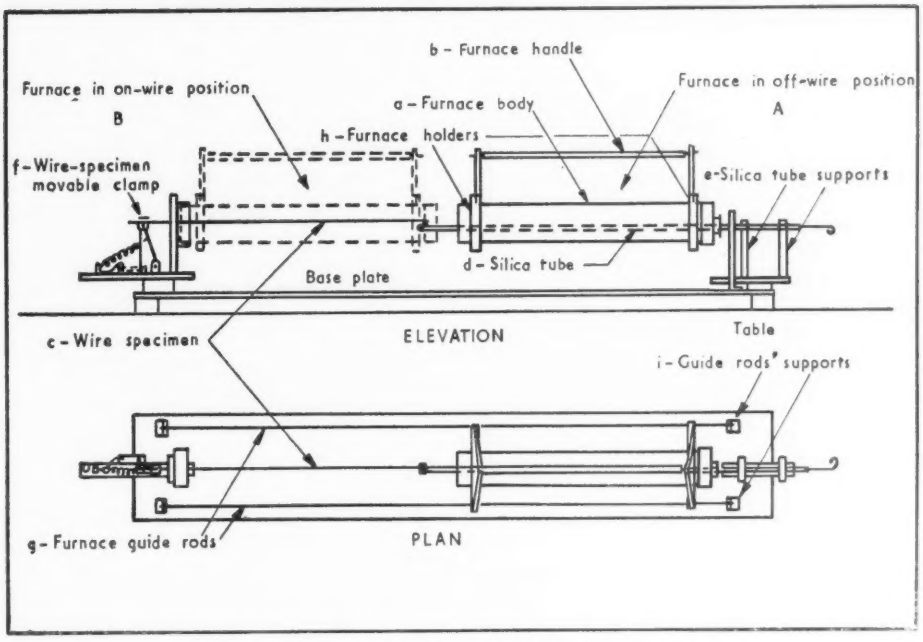


Fig. 2—Diagram of furnace and wire-specimen layout

furnace. During an experiment the hot junction expression has been used throughout the present work. With a Hilger monowavelength celluloid type reflector the resolving power can be almost as good as is obtained in biological microscopes, i.e. $\Delta = \lambda/2\,NA$.

In the present work the method developed by Pearsall (*see* Johnson and Mehl[22]) has been used to determine the S_o values of the various samples of pearlite. However, these values have not been corrected on the basis of Mehl's conclusion that the mean interlamellar spacing is 1·65 times greater than the minimum value. The authors believe that work on a greater variety of pearlites is necessary to establish the general applicability of Mehl's findings and work is at present being carried out to this end.

Preparation of Specimens of Pearlite

The material used in this work was an acid open-hearth eutectoid steel containing 0·83% C, 0·215% Si, 0·015% S, 0·018% P, 0·69% Mn, 0·22% Ni, and 0·05% Cr. This material was used in the form of 14-in. lengths of 0·036-in. dia. wire throughout the experiments. While the authors realize that it would have been preferable to produce pearlites of different interlamellar spacing by the isothermal decomposition of austenite, the equipment to achieve this was not available and, instead, controlled cooling was used. The wire specimens were sealed in steel

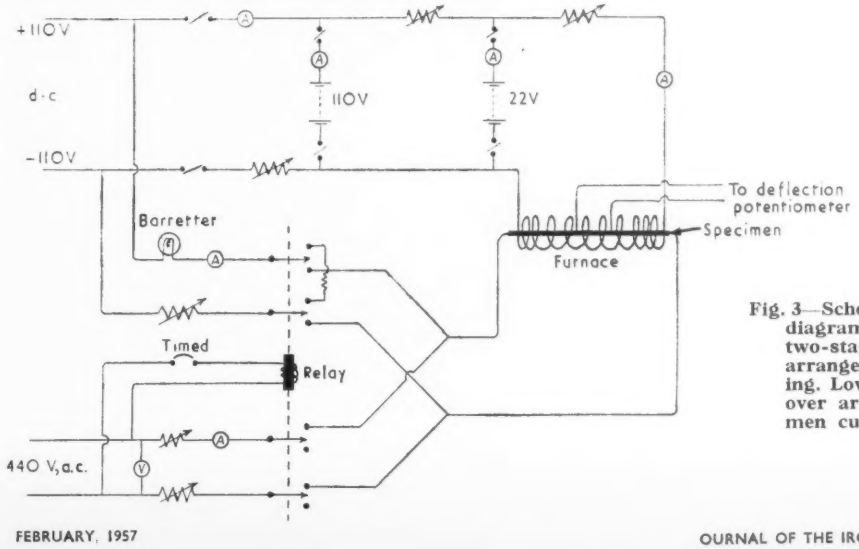
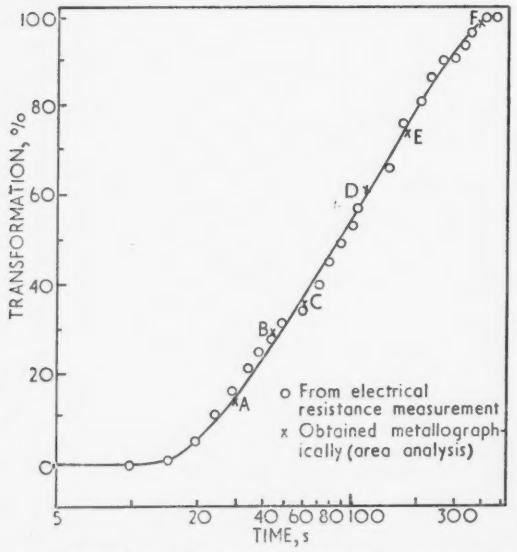


Fig. 3—Schematic electrical circuit diagram. Upper part shows two-stage current stabilizing arrangement for furnace heating. Lower part shows change-over arrangements for specimen current



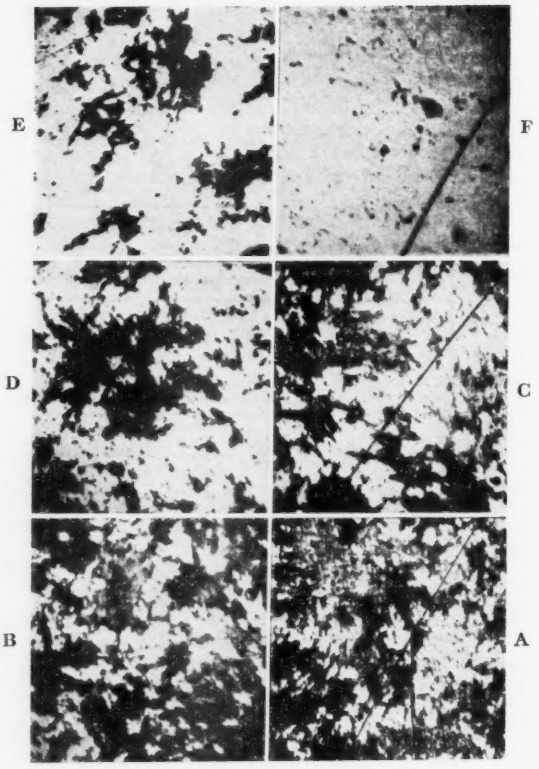


Fig. 4—Transformation/time curve and representative microstructures

Note: The lines on the right-hand micrographs are due to a damaged photographic plate

tubes during this heat-treatment to prevent decarburization. Samples were examined microscopically for uniformity of structure and decarburization and were found to be satisfactory. The interlamellar spacings are given in Table I.

Apparatus

It was originally intended to design the apparatus so that many specimens of pearlite could be transformed to austenite at a large number of temperatures. This work was to be extended to include hypo- and hypereutectoid carbon steels and some alloy steels. The wire specimen was to be heated to the desired experimental temperature in about three seconds by means of a heavy alternating current. The specimen was then to be held at this temperature by a steady direct ' holding ' current and the transformation of pearlite to austenite observed by measuring the change in potential fall along a 1-in. length of wire. Apparatus built with the intention of achieving this proved to be unworkable, because those parts of the specimen which are first transformed to austenite have a higher electrical resistivity than the remaining untransformed material and hence achieve a higher temperature due to the heating effect of the holding current. The apparatus was redesigned to eliminate this effect and as a consequence the speed of working was greatly reduced.

In the new arrangement (*see* Figs. 2 and 3), the specimen was still rapidly heated by means of a heavy alternating current to the desired experimental temperature. Throughout these experiments this current was passed through the specimen for a constant period of time (approximately 3 s), the apparatus being so devised that at the end of this period other electrical circuits were automatically brought into operation. The rapid heating to the various experimental temperatures was secured by changing the magnitude of the preheating current rather than by varying the duration of its application. This was largely a matter of convenience as the timing device, which was a modified gramophone motor, although it gave a very constant interval for a particular setting of the speed adjustment, was not sufficiently flexible to provide a very wide selection of accurate time intervals such as would have been required otherwise. Trial experiments had shown that the specimen was raised from room temperature to the experimental temperature in 3–5 s.

Immediately on completion of the preheating period, a horizontal-tube furnace already at the experimental temperature was automatically moved on guide rails over the specimen. The furnace consists of a silica tube 11 in. long, with a 1·5-in. bore and was internally wound with 0·25-in. by 0·063-in. Kanthal strip. The ends are sealed by asbestos board and aluminium end caps, except for the nitrogen inlet and the exits for the wire specimen and its attendant leads. The aluminium end caps locate the furnace on the horizontal guide rails. The silica tube is lagged externally with asbestos paper which is graded in thickness to promote a uniform temperature within the furnace. Check measurements showed that under equilibrium conditions with the wire specimen *in situ*, the variation in temperature along a 3-in. length of wire was less than 0·1° C. This degree of constancy, naturally, was not attained at the very beginning of an experiment proper.

The furnace temperature was measured using a noble metal thermocouple which was held in a fixed position with reference to the body of the

of this thermocouple lay at about $\frac{1}{4}$ in. in the radial direction from the portion of the wire acting as the specimen. The e.m.f. values of this thermocouple corresponding to various wire temperatures were measured in a preliminary experiment, and thus the furnace could readily be heated to a temperature corresponding to any desired wire temperature. In the preliminary experiment, the wire temperature was obtained by means of a Nichrome Advance thermocouple (wire diameters 0·0048 in.) spot-welded to the wire. However, in the experiment proper, the Nichrome Advance thermocouple was not used and the transformation temperature was taken to be the 'wire temperature' indicated by the noble metal thermocouple.

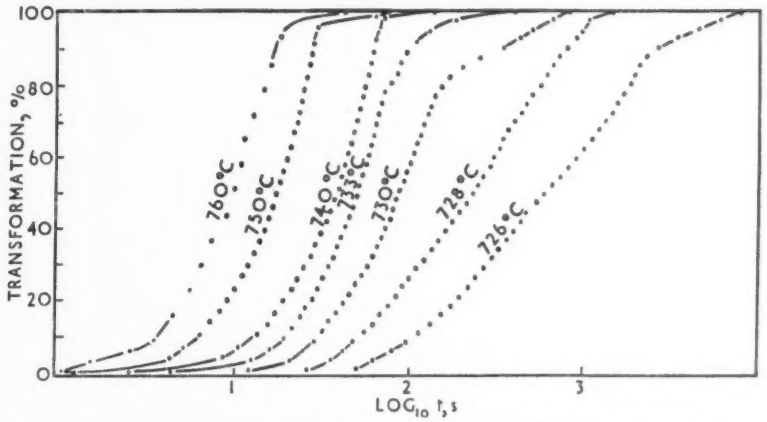


Fig. 5—Transformation *v.* log time curves for pearlite of interlamellar spacing $S_o = 0{\cdot}398\mu$

The furnace was heated by stabilized direct current. The general circuit shown in Fig. 3, which includes a well-known type of two-stage current-stabilizing arrangement, was used. The accumulators were always worked on light discharge and the furnace temperature was adjusted by varying the resistances in series with the furnace. The construction of the resistances and switches in this circuit is very critical as they must pass some 20 A and yet retain constant values of resistance and contact resistance.

To prevent oxidation and decarburization of the specimen, the furnace was purged by a slow, controlled stream of dry oxygen-free nitrogen. Although the authors believe this is not without effect on the specimen, no other simple method could be devised which would avoid undue complications in the apparatus and its manipulation. Argon would have been preferable to nitrogen, but at the time and circumstances of this research, price prohibited it.

The wire specimen is brazed at one end to a $\frac{1}{8}$-in. dia. Monel rod, the latter passing through the furnace when it is in the 'off' position, i.e. before being moved over the specimen. The other end of the wire is held by a hinged arm which is spring-loaded so as to prevent flexing. From this end the current to the wire is led by a flexible conductor. Nickel potential leads 0·0048 in. in diameter are spot-welded to the specimen about 1 in. apart and the transformation is observed by measuring the potential difference between these leads by means of a deflection potentiometer. The exciting current through the specimen is obtained from a 220-V d.c. battery supply and is held at a constant value of about 0·3 A by means of a Barretter. Before the beginning of an experiment this current is passed through a resistance which has a value approximately equal to that of the specimen. Immediately the preheating period is completed, the exciting current is switched automatically to the specimen. This procedure ensures a rapid approach to steady conditions.

Details of the Experiment

The furnace is allowed to reach a steady temperature, which takes about 3 h, with the nitrogen stream flowing. Similarly, the circuit which provides the specimen exciting current is allowed to reach stable conditions, a period of about 30 min being sufficient. The deflection potentiometer is standardized and preset to the value of potential difference expected across the specimen at the experimental temperature. About 1 min before the beginning of the experiment the voltage of the a.c. supply, which is used for preheating the specimen, is measured and the resistance of this preheating circuit is appropriately adjusted.

The specimen is then preheated and, at the end of this period, the furnace moves into position and simultaneously the electrical circuits are made automatically. The potential drop along the specimen is then recorded against time by means of a paper tape chronograph until the transformation is completed. The end of the preheating period is regarded as being zero time with respect to the transformation of pearlite to austenite. After completing the potential drop readings, the furnace is usually moved to the 'off' position and the specimen is water-quenched. This enables the specimen to be examined metallographically to verify that it has been completely transformed to austenite.

A similar technique enables the extent of transformation in partly transformed specimens to be determined by both electrical resistance and metallographic (i.e. area analysis) methods. An example of the agreement between results obtained by these two methods is shown in Fig. 4.

The fraction of pearlite transformed to austenite is obtained from the potential drop measurements by direct proportion, i.e.

$$\% \text{ transformation} = \frac{P - P_1}{P_2 - P_1} \times 100$$

In general, the quantities P and P_2 can be determined quite accurately but P_1 may be influenced by transient electrical effects due to the rapid heating to the experimental temperature. At low tempera-

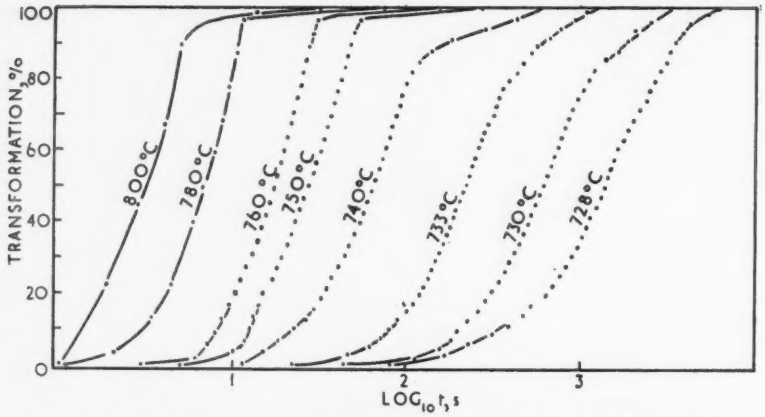


Fig. 6—Transformation *v.* log time curves for pearlite of interlamellar spacing $S_0 = 1{\cdot}333\mu$

tures (725–735° C), where the duration of the incubation period is at least a few seconds, these effects disappear rapidly enough to allow a 'steady' value of P_1 to be established. However, at temperatures above 750° C, there is little doubt that an overlap occurs of electrical effects from both the spurious sources and the transformation proper. In general, time transformation values have been found to be reproducible within about $\pm$ 5%, but at the beginning of transformation, especially at high temperatures, it is doubtful whether this accuracy has been achieved.

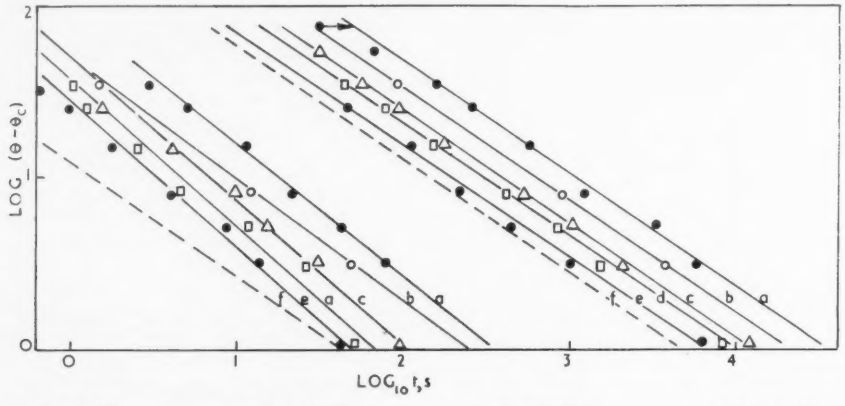
Two of the authors (M.M.L. and C.H.) were responsible for the initial development of the apparatus, which differed in only one respect from the description given above, namely, that the available galvanometer used in conjunction with the deflection potentiometer was somewhat overdamped. This naturally affects the ability of the apparatus to reveal very small rates of change in the potential drop across the specimen and influences the accuracy of determining the beginning and end of the transformation.

RESULTS

Examples of transformation/time curves are shown in Figs. 5 and 6 and other experimental results have been included in Fig. 7. Figures 8–14 represent the results of analysing the transformation/time data, which have been recorded in full elsewhere.[20, 21]

DISCUSSION

The general shape of the transformation/time curves shown in Figs. 5 and 6 is similar to those obtained in nucleation and growth reactions. As mentioned previously, the general accuracy is influenced by the accuracy with which the beginning of the transformation can be determined. At high temperatures, the effects due to the rapid preheating of the specimen may affect the accuracy with which the beginning of the transformation can be determined owing to the very short incubation period. In addition, at temperatures little above the A_1 a very small change in specimen temperatures seriously alters the reaction rate and the incubation period. It is difficult to assess the overall accuracy of the results. From the results of control experiments which were undertaken before the experiments to establish the experimental conditions, the authors found that time/transformation values were reproducible within about $\pm$ 5%, other experimental variables being constant. This was regarded as satisfactory when the number of significant experimental variables is considered.



a. $S_0 = 1{\cdot}333\mu$ *b.* $S_0 = 0{\cdot}865\mu$ *c.* $S_0 = 0{\cdot}489\mu$ *d.* $S_0 = 0{\cdot}398\mu$
e. $S_0 = 0{\cdot}185\mu$ *f.* $S_0 = 0\mu$ (from $\log t = P + QS_0 - R\log(\theta - \theta_e)$)

Fig. 7—Times of beginning and end of transformation shown as a function of reaction temperature. Groups of results on left and right correspond to beginning and end of transformation respectively; θ = reaction temp., $\theta_0 = A_1$ temp. of steel (725°C)

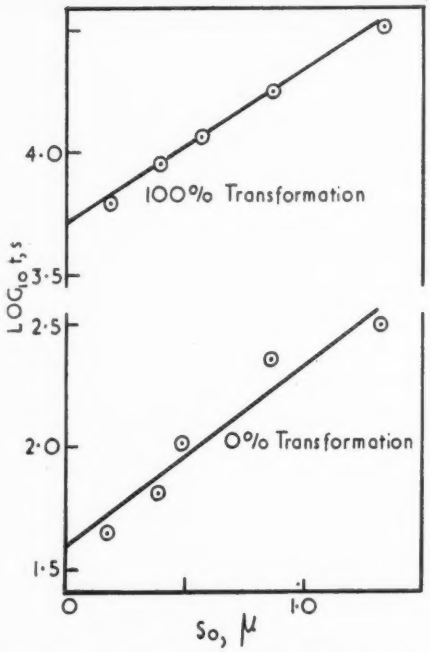


Fig. 8—Log time *v.* interlamellar spacing S_o when log $(\theta + \theta_c) = 0$

Mathematical analysis of the results yields the following equations:

$$\log_{10} t \text{ (0\% transformation)} = 1{\cdot}60 + 0{\cdot}71\, S_o - 1{\cdot}5 \log_{10} (\theta - \theta_c)$$

$$\log_{10} t \text{ (100\% transformation)} = 3{\cdot}72 + 0{\cdot}6\, S_o - 1{\cdot}5 \log_{10} (\theta - \theta_c)$$

where t = time in seconds, S_o = mean interlamellar spacing, θ = transformation temperature, and θ_c = A_1 temperature of the steel.

These equations were deduced from Figs. 5–8 and, allowing for the scatter of the experimental points,

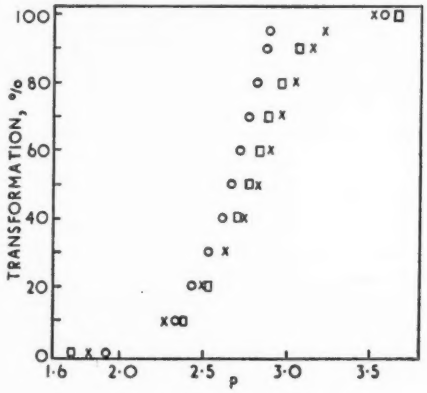


Fig. 9—Values of P from $\log t = P + QS - R \log (\theta - \theta_c)$ plotted against transformation, %

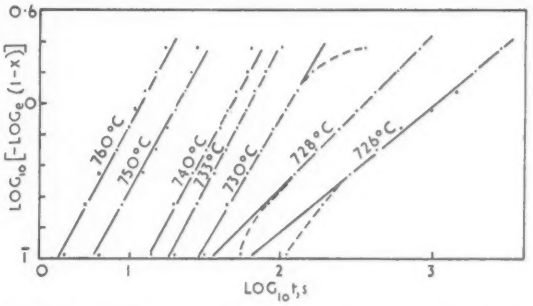


Fig. 10—Analysis of transformation time data using Avrami's formula. Fraction transformed = $x = 1 - \exp(-Bt^k)$. $S_o = 0{\cdot}398\mu$

the authors believe that the general equation given below is applicable:

$$\log_{10} t = P + 0{\cdot}66\, S_o - \frac{3}{2} \log_{10} (\theta - \theta_c)$$

where $P = 1{\cdot}60$ at the beginning and $P = 3{\cdot}72$ at the end of the transformation. Thus P may be regarded as a shape factor and, when plotted against fraction transformed, in theory may be used as a master reaction curve, enabling transformation/time curves for any pearlite to austenite transformation to be predicted, provided that the reaction temperature and the mean interlamellar spacing of the pearlite are known. Curves of P plotted against fraction transformed for actual examples selected from the experimental results are shown in Fig. 9. The fact that these curves are not identical is due to errors in the original experimental results and the approximations used in their mathematical manipulation; under these conditions, however, the authors regard the agreement as reasonable. It is perhaps appropriate to emphasize here the major influence incurred by errors in temperature measurement. The transformation is dependent on $(\theta - \theta_c)$ and small errors in temperature measurement may introduce large errors in computed values of $(\theta - \theta_c)$, especially when $(\theta - \theta_c)$ is small. The present results cannot be used as a basis for calculating nucleation rates and growth velocities but they can be analysed using the limiting equations from theories due to Johnson and Mehl[22] and Avrami[23]:

(1) Johnson–Mehl, assuming N constant, for wire $X = 1 - \exp(-f G N^2 t^2/2)$

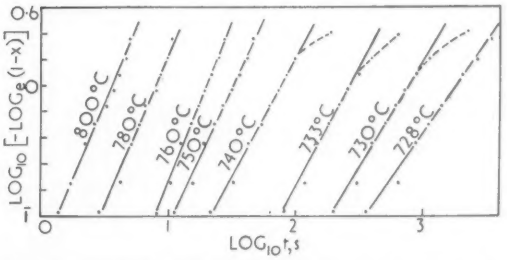


Fig. 11—Analysis of transformation/time data using Avrami's formula. Fraction transformed = $x = 1 - \exp(-Bt^k)$. $S_o = 1{\cdot}333\mu$

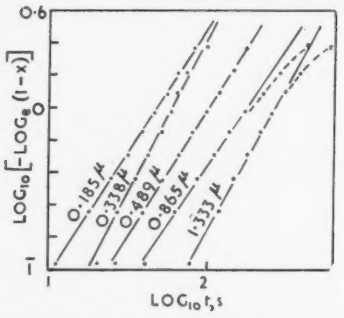


Fig. 12—Analysis of transformation time data using Avrami's formula. Fraction transformed = $x = 1 - \exp(-Bt^k)$. Transformation temperature = 733° C

where X is the fraction transformed, G is the growth velocity, N is the rate of nucleation, f is the diameter of the wire, and t is the time.

(2) Avrami, $X = 1 - \exp(-Bt^k)$

B and k are parameters, $k = 1$–2 for wire, 2–3 for sheet and 3·4 for ' three-dimensional ' solid.

Theoretically, it ought to be possible to obtain information concerning the joint effect of nucleation and growth rates by comparing the Johnson–Mehl equation for wire with the corresponding Avrami equation. However, this comparison does not yield very satisfactory results, as the values of k obtained from the present experiments vary between about 0·8 and 2·0, the former referring to results obtained at temperatures little above the A_1 temperature. This variation in k influences the calculated values of B considerably. It is not unreasonable to expect B to increase with temperature, provided that the interlamellar spacing remains constant, and this general expectation is realized on calculating B from transformation curves where the values of k are reasonably constant. However, variations of k may cause the calculated values of B to decrease with increasing temperature, as shown in the lower part of Fig. 14. This effect may be explained in the following manner. For pearlite with large interlamellar spacing at low transformation temperatures, the number of austenite nuclei involved may be relatively small and growth

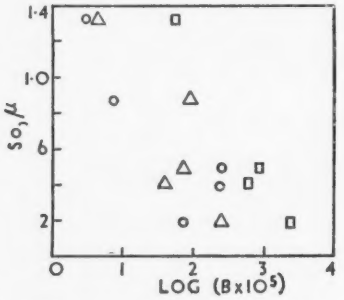


Fig. 13—Plot of B from Avrami's formula against interlamellar spacing S_o

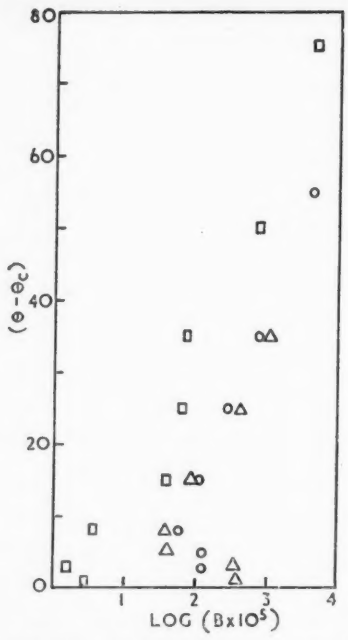


Fig. 14—Plot of B from Avrami's formula against transformation temperature

in the radial direction in the wire may cease at an early stage in the transformation. On this basis the reaction may be regarded as being ' uni-dimensional ' and k would have a value in the region of 1. Conversely, with fine pearlite and high transformation temperatures, the number of nuclei involved will be greater and it is less reasonable to regard the reaction as ' uni-dimensional.' Hence k would be expected to be greater than one and may be conceivably greater than two. If this reasoning is correct then the value of k for the initial stages of a low-temperature transformation ought to be approximately equal to the general value of k for a high-temperature transformation considered as a whole, because, under these conditions, except for the effects of impingement of adjacent austenite grains, growth will be approximately ' three-dimensional,' and the transformation will not be greatly influenced by the dimensions of the wire specimen. Inspection of figures tends to support rather than disprove this deduction.

The quantity B is a function of both growth velocity and nucleation rate. Figure 13 shows that the value of B is greater for fine than coarse pearlite, which is in agreement with general expectation. Figure 14 shows that values of B increase with $(\theta - \theta_c)$, i.e. with increasing temperature, for values of $(\theta - \theta_c)$ greater than 10. This again is in agreement with general expectation.

CONCLUSION

An equation of the general form

$$\log t = P + QS_o - R \log (\theta - \theta_c)$$

is suggested as representing the transformation of lamellar pearlites to austenite at super-critical temperatures. Q and R are constant but P is a parameter whose value varies between limits and depends on the fraction of pearlite transformed.

General agreement between the present experimental results and the limiting equations of the Johnson–Mehl and Avrami theories has been obtained for transformation temperatures significantly higher than 735° C. Below this temperature the dimensions of the specimen are thought to have influenced the progress of the reaction and so lessening the general agreement.

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Wear Protection of Mild Steel by Phosphating

By J. W. Midgley, M.Sc., D.I.C.

INITIALLY, PHOSPHATING WAS USED solely as a treatment before the application of paint or stain for protection against corrosion. For this purpose a relatively thin deposit of about 3×10^{-4} cm is suitable, and a zinc phosphate bath is generally used.

More recently, in 1936–37 it was found that if steel parts to be deep-drawn or pressed were phosphated, much less wear on the dies and often a lower power consumption was obtained. Indeed, phosphate coatings have been found to be generally advantageous in reducing the wear of sliding steel surfaces.[2–7]

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Mr. Midgley was with the Chemical Engineering Department of Imperial College, London, when this paper was written. He is now with The English Electric Co.

SYNOPSIS

A study is made by microscopy of the change in the nature of mild-steel surfaces phosphated in an accelerated iron phosphate, or an accelerated iron manganese phosphate bath, and of the changes during subsequent wear tests.

It is shown that phosphating the surface at first etches it, giving rise to interconnecting surface channels surrounding plateaux which become covered with phosphate crystals. On subjecting the surface to wear, the phosphate crystals are very soon removed, leaving the plateaux to form the bearing surface.

The inference by Roosa and others, that the process results in a bearing surface depleted in α-iron has not been substantiated. The composition of the plateaux is not appreciably different from that of the bulk mild steel.

The effect is shown of pearlite and of strain in the α-iron grains on the coating produced, and the effect of the distribution of these on the coating and its wear properties is discussed.

The wear protection shown to be present after running-in the phosphated mild steel under the conditions used can neither be attributed to the coating acting as a solid lubricant nor to surface hardening, but is principally due to the controlled channelling of the surface caused by the phosphating process. 1242

The mechanism affording this protection still remained obscure although the results obtained show that the coated steel possesses the following qualities:

(i) The unworn coating absorbs and holds a considerable quantity of lubricant on, or near to, the bearing surface

(ii) Unlubricated phosphated steel will initially run for a short period under conditions where unphosphated steel seizes immediately.

In addition, Roosa[1] reported a preferential removal of ferrite during the process. This is said to be beneficial because it is the constituent which most readily forms welds.

An important feature which is beyond the scope of the present paper is that new oiled phosphated bearings may be stored with less fear of atmospheric corrosion.

Other suggestions have been made[6, 7] to account for the wear-protective action, but they are vague, and the experimental evidence on which they are based is not clear.

The practical importance of elucidating this problem will be appreciated when it is realized that it is still not known why phosphating does not always give the required wear protection. It is also of great practical and scientific interest to discover the mode of action of one of the most successful methods of wear protection of steel, especially to enable a general procedure for wear protection to be developed.

The results of the present investigation lead to the clear conclusion that under the conditions used, and no doubt more generally, the wear protection produced by phosphating after running-in, is mainly due to channelling of the surface by the etching action of the process. This conclusion is based on a study of the growth of the phosphate deposit and of the subsequent wear properties.

EXPERIMENTAL DETAILS

Two different phosphating treatments were chosen for investigation: (*a*) an accelerated iron phosphate bath; (*b*) an accelerated iron manganese phosphate bath, designated by the manufacturers C.2 and P.L. respectively. These are proprietary processes developed industrially and well known for their qualities of wear protection. The baths consist of equilibrium solutions of iron, phosphate, and nitrate, with or without the presence of manganese ions in the ratio of Mn/Fe = 3, and a NO_3/PO_4 ratio of 0·07. The solutions were contained in mild-steel tanks maintained at a temperature of 96–97° C, i.e. within a few degrees of their boiling points, to prevent the free precipitation of the sparingly soluble higher phosphates of iron and manganese.

The specimens used were $\frac{1}{2}$-in. dia. discs, $\frac{1}{4}$-in. thick, cut from the same 0·15% C mild-steel rod, except where otherwise stated. They were abraded on emery cloth and papers under benzene, down to 3/0 emery, and when required they were polished on Selvyt cloth impregnated with levigated alumina lubricated with distilled water. They were then degreased with liquid acetone and benzene, and immersed for 30 s in boiling distilled water. (It had already been verified that this period was adequate to raise them to the temperature of the phosphating bath.) They were phosphated for the required time, dipped in boiling distilled water to remove any surplus processing solution, dried by evaporation, and given an acetone rinse.

A Vickers projection microscope was used for the optical examination of the deposits.

The wear-testing machine used is shown in Fig. 1. This machine was constructed in 1938 under the direction of Professor G. I. Finch. Wear is measured by the loss in weight of the disc pressed by a loaded spring on to a rotating circular plate. The bearing so formed is lubricated by oil fed at a controlled rate on to the plate, of which the linear speed (relative to the disc) can be varied up to a maximum of 1300 cm/s. In the present experiments a nominal pressure of 3 kg/cm^2 was applied, the speed was 1100 cm/s, and as the discs were constrained from rotating they were subject to unidirectional wear. Preliminary experiments showed that the wear-protective qualities endowed by phosphating mild steel were, with the above apparatus, most obvious when a lubricant of low viscosity, such as kerosene, was used. This liquid was therefore used throughout as lubricant, and it was used under flooding conditions.

Since the wear of two bearing surfaces is a function of the nature of both surfaces, careful attention has been paid to the influence of the plate finish on the wear of the specimen discs. The wear plate finish initially adopted was obtained by facing-up the mild-steel plate in a lathe and finishing off flat by grinding against a flat steel plate covered with fine carborundum paste. The surface of the wear plate was then thoroughly cleaned with petroleum ether until no staining occurred on evaporation of droplets of this liquid solvent on the plate. In spite of the care taken to remove all traces of loose carborundum from

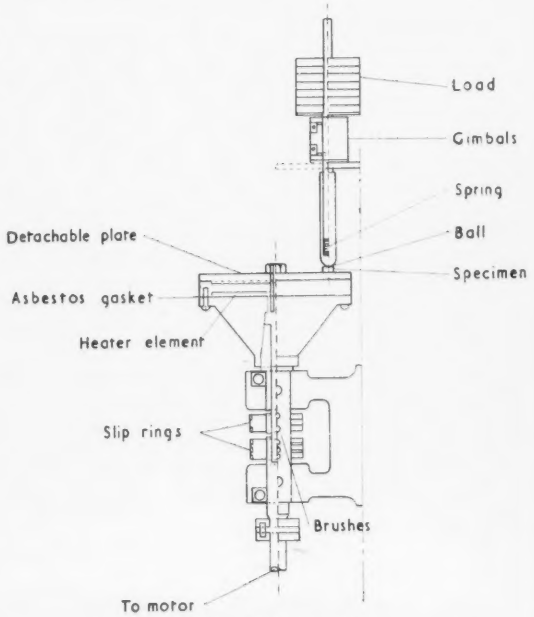


Fig. 1—Wear machine

the surface, it was found that excessive wear of the specimen occurred using wear plates prepared in this manner. The lubricant used in these experiments was medicinal liquid paraffin. Since excessive wear of the lathe-tool also occurred when the plates were refaced, it was concluded that this type of finishing causes a large number of silicon carbide particles to become embedded in the relatively soft mild-steel surface (Mohs hardness of mild steel, 6–7; of silicon carbide, 9·5). The only other surface finish which could be conveniently applied to such plates was by facing the plate on the lathe. The disadvantage of such a finish is that it cannot be absolutely uniform because of wear of the tool during the facing process. Nevertheless the finish obtained is similar to that often adopted in practice for bearing surfaces, and the reproducibility of such a surface is probably at least as good as that which would be possible using any other type of surface finish. In the wear tests described below, therefore, a standard procedure of lathe finishing was adopted. The unusually high reproducibility and consistency of the wear curves obtained show that the procedure adopted was suitable for a detailed study of the wear process.

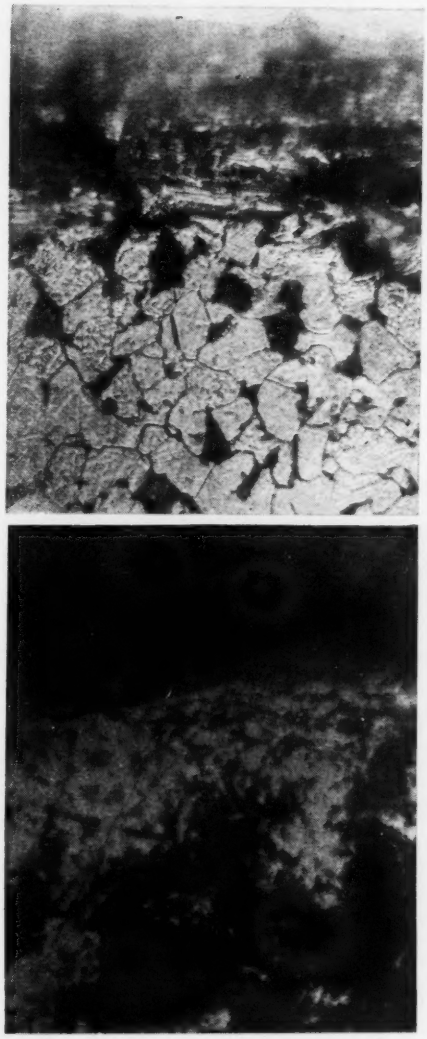


Fig. 2—(*a*) Polished mild steel etched 2% nital; pearlite and α-iron grain boundaries appear black (*b*) As (*a*), repolished and phosphated 2 min in iron phosphate bath Both × 600

RESULTS

Formation of the Deposit

The broad outline of the successive stages of the formation of the deposit on polished mild steel is found to be as follows. Initially the grain boundaries and many of the α-iron (ferrite) grains are noticeably attacked by the solution, while the pearlite, or more correctly the cementite,[8] appears to be unaffected, as will be seen by comparing Figs. 2*a* and *b*. After about 3 min in the iron manganese bath, or 6 min in the iron bath, block-like phosphate crystals 10–30 μ dia. and 10–15 μ high have formed. When the treatment has proceeded for about twice the above periods respectively, the formation of foliaceous crystal aggregates begins on about half of the surface, while etching of the rest of the surface continues. These aggregates can attain up to 100 μ in dia. and 0·5–2 μ in thickness. These investigations showed that the process may be considered complete after about 12 min in the iron manganese bath, and 20 min in the iron bath, when about 75% of the surface is covered by deposit crystals. Abraded mild steel became phosphated at about twice the above rates. The crystal size and coverage quoted above have been determined from observations made on about 50 specimens. The values vary within the limits stated from specimen to specimen and over the different parts of the same specimen. Single micrographs cannot fully illustrate all the variations in the development of the phosphate deposit, but Figs. 2–5 show that the development of the principal features described above occurs during the phosphating of one particular area. This area was identified by the two surface scratches which cross obliquely in the top left-hand corner of the micrographs. As will be seen, the fully phosphated surface is covered with an apparently haphazard jumble of crystals. Because of this it was impossible to decide what determined the nature of the final coating without studying its growth in some detail.

The process of deposition is considered in the discussion below, and indicates that it is electrolytic, resulting from local cell action. It is to be expected therefore, that the nucleation sites would be associated with factors that give rise to local potential differences of sufficient magnitude. In the case of the mild steel used in the investigation, these might include pearlite, strained regions, and impurity sites.

To determine whether the nucleation sites may be associated with the pearlite, a polished mild-steel specimen of low pearlite content was phosphated in the iron manganese bath for the short period of 3 min. Microscopic examination showed that the large, angular, plate-like, transparent phosphate crystals were superimposed on the larger of the bright

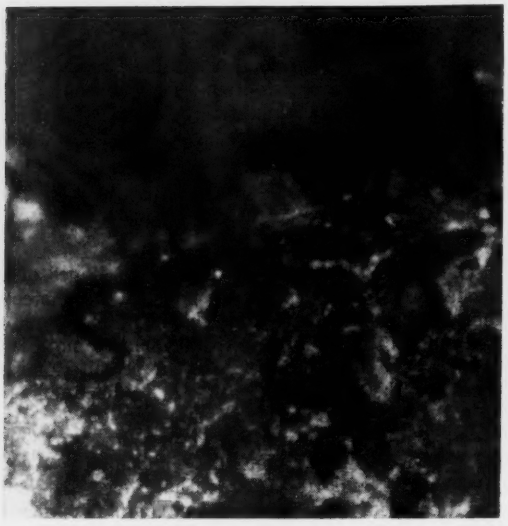


Fig. 3—As Fig. 2*a*, phosphated for 6 min × 600

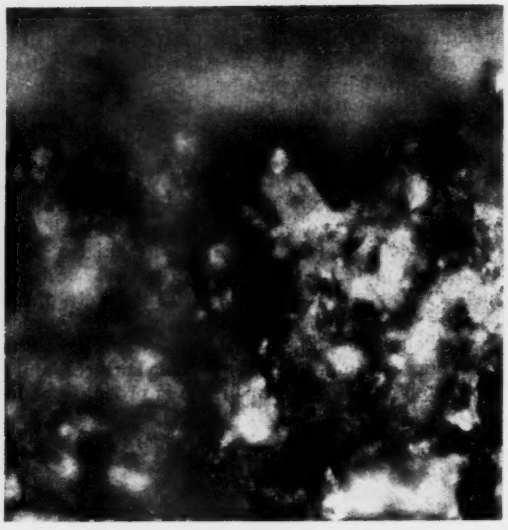


Fig. 5—As Fig. 2*a*, phosphated for 20 min × 600

areas of the substrate, which were identified as pearlite. A photomicrograph of the surface is shown in Fig. 6.

Comparison of the deposits formed on polished mild steel with those formed on abraded mild steel phosphated for the same times, as shown in Figs. 5 and 7, indicated that the surface finish also has an appreciable effect on the form of the deposit. When scratches were made on a polished mild-steel surface it was found that the reaction proceeded fastest and nucleation occurred first in the strained regions adjacent to the scratch rather than at the pearlite grains. An example of this experiment has already been illustrated in Figs. 2–5. By comparison of Figs. 3 and 4 in that series it will be seen that the block-like transparent phosphate crystals have first formed adjacent to the scratch which runs across the top half of the micrograph. The raising of the potential produced by the scratch is therefore seen to be sufficient to affect the course of the reaction.[9] The discussion of this result is given later.

Because of the brittle nature of the deposit it has not yet proved possible to make a section of the surface, but the surface profile has been studied microscopically. The crystal thickness (to $\pm 0{\cdot}5$ μ) was obtained from the change in height of the microscope when focused on the upper and lower

Fig. 4—As Fig. 2*a*, phosphated for 12 min. × 600

Fig. 6—Phosphate crystals initially formed on pearlite × 600

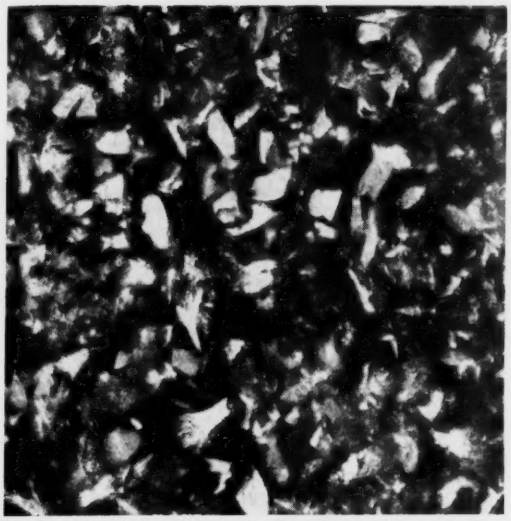


Fig. 7—Abraded mild steel phosphated in iron phosphate bath for 20 min × 600

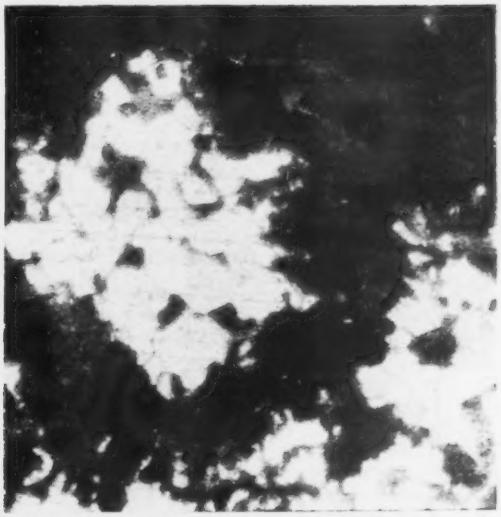


Fig. 9—As Fig. 8*d*, lightly polished with alumina, etched in nital × 600

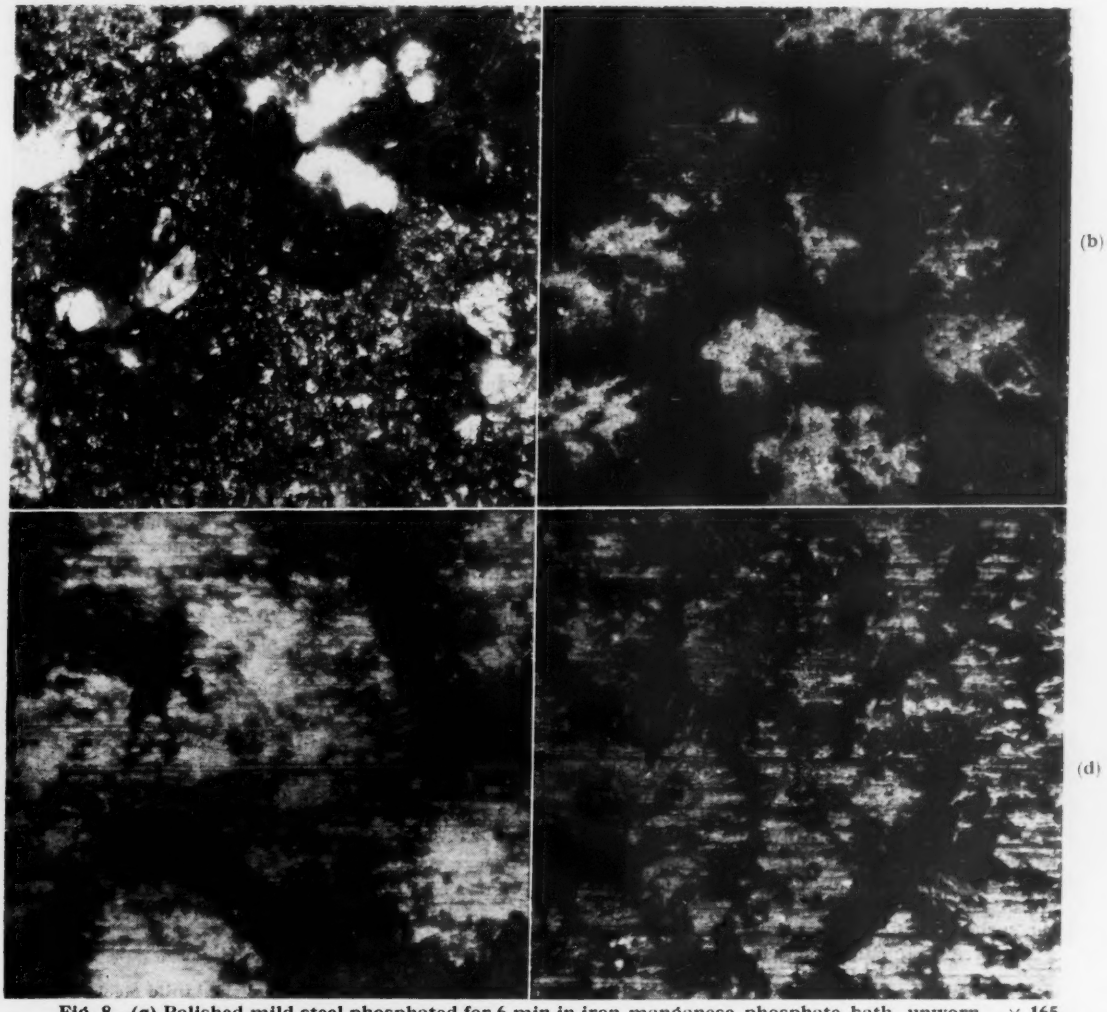
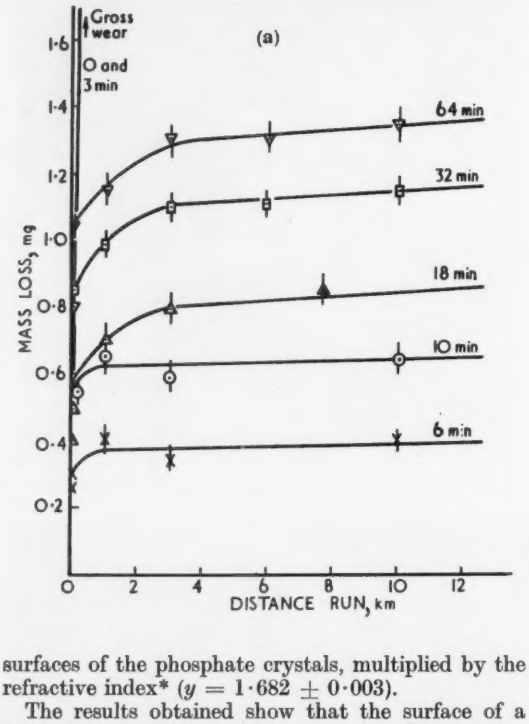


Fig. 8—(*a*) Polished mild steel phosphated for 6 min in iron manganese phosphate bath, unworn. × 165
(*b*) As (*a*), worn for 10^{-2} km × 165 (c) As (*a*), worn for 20 km (note increase in size of bearing plateaux) × 165
(*d*) Polished mild steel phosphated for 30 min in iron manganese phosphate bath, worn for 20 km × 165



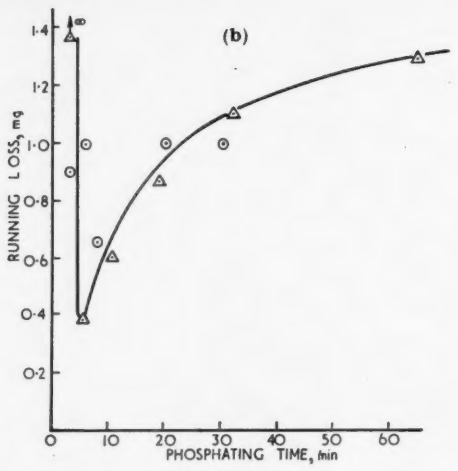


Fig. 10—(*a*) Wear curves for polished mild steel phosphated for different times in iron phosphate bath

(*b*) Running-in mass loss/phosphating time for polished mild steel phosphated in iron phosphate bath

surfaces of the phosphate crystals, multiplied by the refractive index* ($y = 1{\cdot}682 \pm 0{\cdot}003$).

The results obtained show that the surface of a fully phosphated specimen consists of remaining plateaux of mild steel 10–15 μ high and 50–100 μ dia., covering about half the surface, and it is on these that the phosphate crystals are deposited. The plateaux are large compared with the individual α-iron or pearlite grains and contain a number of these grains.

Wear Characteristics

Figure 10*a* shows the relation between wear and distance run for polished mild steel phosphated in the iron phosphate bath for different periods. It will be seen that unphosphated mild steel will not run-in under the conditions imposed, whereas the phosphated mild steel runs-in satisfactorily. The wear conditions were thus suitable for investigating the protective action of phosphating. Similar results were obtained from specimens phosphated in the iron manganese bath as shown later. Defining the running-in period as ' that initial period during which the wear rate is high and varying rapidly,' it will be seen that the running-in loss depends upon the time of phosphating. This dependence is shown more clearly in Fig. 10*b*. The values given by the two baths probably lie on two separate curves. These curves, however, are so close together that in the figure a single curve is drawn as the mean for the two sets of observations. As will be seen, minimum running-in loss is at a phosphating time corresponding approximately to that during which only etching of the surface occurs. The results are discussed later.

The wear rate subsequent to running-in, for fully phosphated specimens, is the same within the experimental error for the two baths, being $(4 \pm 1) \times 10^{-6}$ g/km.

The wear curves in Fig. 10*a*, especially those of specimens phosphated for only a short period, show signs of a maximum at the end of the running-in period (at about 3-km run) but the possible error (0·05 mg) of the mass loss determinations was not small enough to show this detail adequately, hence smooth curves are shown in the figure. Greater sensitivity of weighing (± 0·01 mg) made possible by use of a semi-microbalance, has verified the reality of this maximum, as shown in Fig. 11. Further experiments are being done to elucidate the origin of this feature.

Microscopic examination of the surfaces during the wear runs showed that the phosphate crystals are rapidly removed from the plateaux tops, the bare mild-steel surface of which are exposed in less than

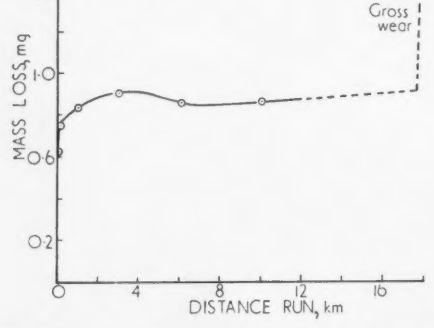


Fig. 11—Wear curve for polished mild steel phosphated in iron manganese phosphate bath for 3 min

* Measured by Mr. Jobbins of the Geological Museum, South Kensington.

10^{-2} km run, as shown in Figs. 8*a* and *b*. This is after only a small part of the running-in period of 3 km. The plateaux seen in Figs. 8*b–d* are bright in appearance against the dark background of the channels between them. Wear tracks can be clearly seen across the plateaux, showing that the plateaux are supporting the load. The plateaux are not worn down completely during the running-in, as will be seen from Fig. 8*c*, a decrease from an original height of 15 μ to 10 μ being typical. Figure 8*d* shows a heavily phosphated surface which had been run-in; here, too, it will be seen that plateaux remain and support the load after running-in. Positive identification of the metallographic nature of the bearing surfaces of the plateaux was obtained by lightly polishing a run-in specimen and etching in 2% nital. The resulting surface is shown in Fig. 9. The α-iron grain boundaries and the pearlite are readily identified, and it is evident that the composition of the plateaux is about 75% α-iron, which is identical with that of the bulk of the mild steel.

Barwell[4] has found that previously unworn phosphated steel will run for a short period without lubrication whereas unphosphated steel seized immediately under the same conditions. It was not known whether this property would also be exhibited by phosphated mild steel *after* running-in.

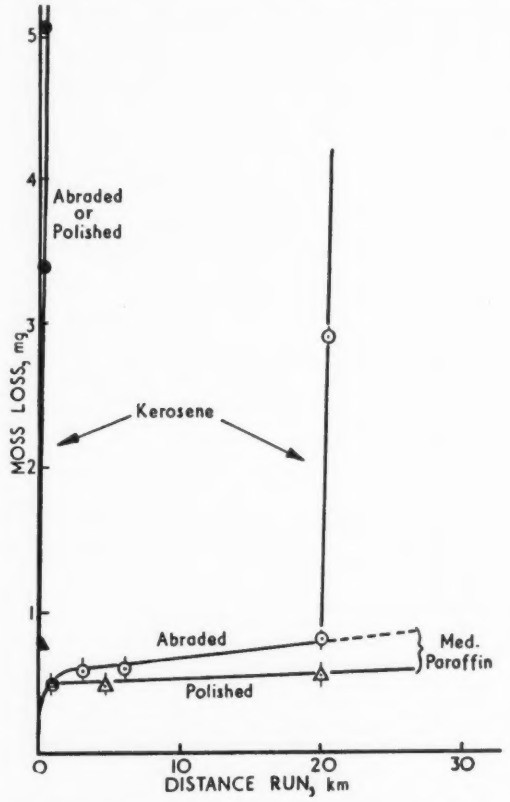


Fig. 12—Wear curves for polished and for abraded unphosphated mild steel lubricated with kerosene or medicinal paraffin

Table I

HARDNESS TESTS ON UNPHOSPHATED MILD STEEL

Surface		Hardness, D.P.N.
Etched unworn mild steel	Ferrite	100
	Pearlite	250
Lightly polished mild steel		190
Plateaux of mild steel run-in after fully phosphating in:	Iron manganese bath	230
	Iron bath	330
Phosphate crystals fractured on indentation		...

In a number of cases in the present investigation, the supply of kerosene to the bearing was stopped after the surface had been run-in. Gross wear occurred after 2 or 3 s, i.e. no longer than it would take for the lubricant to escape from the bearing. No evidence has been found of any protective action under these circumstances. The specimens were typical of those used in the experiments above, and included both initially abraded specimens and polished specimens fully phosphated in the iron manganese or iron phosphate bath and then successfully run-in.

Figure 12 illustrates another important point. When an unphosphated specimen, which appeared to be run-in after about 4 km using medicinal paraffin as lubricant, was then run-in still more fully to 20 km and the lubricant then changed to kerosene, gross wear occurred immediately, followed by seizure. But, as shown above, phosphated surfaces retained their low-wearing properties long after they had reached the run-in stage, even though the lubricant used throughout was kerosene.

Surface hardening, e.g. by carburizing or nitriding, is often used as a means to reduce wear. It seemed possible that ploughing-in of the phosphate layer might enhance surface hardness and be an important factor in wear protection. Hardness tests were therefore made on unphosphated mild steel and on run-in phosphated mild steel. As the depth of hardening could only be small, a G.K.N. microhardness indenter with the lightest possible loading on the diamond (10–30 g) was used to determine the hardness of individual grains of the α-iron, and the pearlite. The depth of penetration was only about 1·5 μ. The results, summarized in Table I, agree with published data[10] for these types of surface.

It will be seen that compared with a surface hardness of 900–1150 D.P.N. for nitrided steel, the hardening observed with the run-in phosphated surface is negligible. The brittle nature of the phosphate crystals no doubt accounts for their rapid removal during the running-in process as observed above, and it is probable from these results that very little of the coating is ploughed into the surface.

DISCUSSION

Discontinuous Nature of Bearing Surface

The above study of the nucleation and growth of the phosphate deposit shows that the combination of etching and deposition which occurs, results in inter-

connecting channels being made on the surface, and these surround plateaux on which phosphate crystals are deposited. The plateaux are large compared with the individual α-iron or pearlite grains of the mild steel used, and are shown by the above experiments to be identical in composition with the bulk of the specimen. Microscopic examination made after the phosphated mild steel had been subjected to wear, showed wear tracks crossing the plateaux, indicating that it is these plateaux which form the bearing surface. In addition to the plateaux there are numerous small pearlite peaks in the channels, but the heights of these are less than those of the plateaux and they do not contribute to the bearing surface. The statement by Roosa and others that the wear protection is in part associated with the preferential removal of α-iron is therefore not true for the steel investigated here. Some preferential removal of α-iron was found to occur initially, but the roughening produced was negligible compared to the larger scale-roughening which subsequently occurred during processing.

The present experiments have shown that the nature of the fully-phosphated bearing surface was such that the treated specimens ran-in, and continued to run satisfactorily, using a lubricant (kerosene) of much lower viscosity than that possible with untreated mild steel run-in under the same wear conditions. Untreated mild steel would neither run-in using kerosene nor would it continue to run if, after running-in with a more viscous lubricant (medicinal paraffin), the lubricant was then changed to kerosene. This strongly suggests that the discontinuous nature of the bearing surface produced by phosphating facilitates the establishment of hydrodynamic or thin film lubrication.

It has been shown how the running-in mass-loss depends on the phosphating time (Fig. 10*b*), and it is evident from these results that substantial wear protection is afforded by phosphating for so short a period that the surface is little more than preferentially etched in certain areas. Many examples are known where increase of surface roughness by physical, or chemical, means gives substantial wear protection, cf. Martz,[11] but the present investigation is the first to show that the phosphate wear protection which is still present after running-in, is largely, if not entirely, associated with this factor.

The experiments show that with a fully phosphated surface, the plateaux survive the running-in period and continue to form the bearing surface after the surface is run-in. If the surface is under-phosphated, the plateau height is correspondingly less. In such cases the plateaux may soon be worn away over an appreciable part of the bearing surface. When this occurs seizure results as shown by the wear curve (Fig. 11) given by mild steel phosphated for only 3 min in the iron manganese bath. In this case, owing to the short period of etching, the plateaux heights at the beginning of the wear run were only 4–6μ, about one third of the height in a fully phosphated specimen; and when, after 17·5-km wear run, the plateaux were worn right down over about half of the surface, rapid wear and seizure occurred (Fig. 11).

An electron-diffraction and microscopic study is also being made at different stages of the wear runs. The results so far obtained confirm the above results and when complete will be reported.

Formation of Bearing Plateaux

The processing solutions used in these experiments contain (*a*) primary, secondary, and tertiary phosphates of bivalent iron; (*b*) iron and manganese. The baths reach an equilibrium, as shown in the equations below, and the equilibrium state depends on the temperature of the solution and the relative concentrations of the chemicals present.

$$3\ R.(H_2PO_4)_2 \rightleftharpoons 3\ R.HPO_4 + 3\ H_3PO_4$$
$$3\ R.HPO_4 \rightleftharpoons R_3(PO_4)_2 + H_3PO_4$$

The higher phosphates are only slightly soluble in water so that the presence of free H_3PO_4 is necessary, and the temperature has to be near the boiling point to avoid their precipitation as a sludge,[12] hence the desirability of preheating the specimens by immersion in boiling water.

The formation of the coating appears to proceed as follows. On immersing the preheated mild steel in the bath the more reactive, or anodic, areas of the surface are attacked, and the remaining areas presumably act as cathodes for the corrosion process. Later, when there is a sufficient depletion of the local hydrogen ion concentration in the regions of the cathodic areas, the above reactions are driven to the right and deposition of the higher phosphates occurs in these regions. Chunky crystals are formed first, and it has been observed that these are sited on some of the larger pearlite grains, presumably because of the high reaction rate caused by the iron carbide (Fe_3C), and the α-iron laminations in the pearlite. Deposition then occurs on, and adjacent to, larger unattacked (cathodic) areas, each of which contain a number of α-iron and pearlite grains. These areas are soon surrounded by anodic area channels 10–15μ deep.

Since it has been shown above that the plateaux form the bearing surface, it is of great interest to try

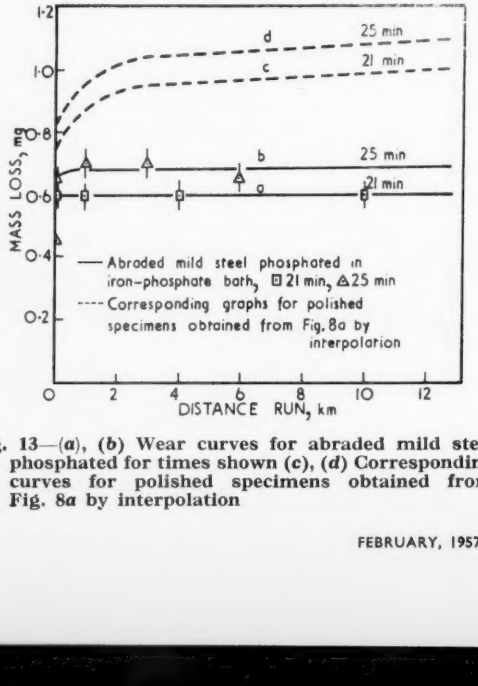


Fig. 13—(*a*), (*b*) Wear curves for abraded mild steel phosphated for times shown (c), (*d*) Corresponding curves for polished specimens obtained from Fig. 8*a* by interpolation

to determine what factors influence their size, distribution, and height.

Although the pearlite does initially affect the reaction process this does not appear to have an important effect on the formation of the bearing plateaux. One important factor is likely to be surface strain, since it is well known that the stored energy in strained areas causes them to be anodic with respect to similar but less-strained areas. In the present investigation the acceleration of the etching and phosphate deposition by strain has been clearly demonstrated by the study of the processing rate of different regions of a scratched, polished surface and also by the fact that the processing rate of abraded surfaces is observed to be about twice that of polished surfaces. The effect on the wear properties will be seen on comparing Figs. 10*a* and 13. Abraded specimens appear to run in quicker with a smaller running-in loss than polished specimens phosphated for the same period ($\sim\frac{1}{2}$ km; 0·6 mg) and (3 km; 0·9 mg) respectively. It is hoped to extend this interesting aspect of the work later, as the results show that surface finish can have an important effect on the wear characteristics of phosphated steel.

Non-occurrence of Phosphate Glass

After running-in satisfactorily, the surface of phosphated mild steel assumes a characteristic black shiny appearance, similar to the so-called 'phosphate glass.' In the present investigation no trace has ever been found of the transparent surface layer reported by Durer and Schmidt[13] and said to be caused by coalescence of the phosphate crystals. The formation of such a layer in the present experiments would indeed be most surprising, since it has been found that the crystals are exceedingly brittle, and soon removed from the surface during the wear run. It has been found that the shiny black appearance was caused by a combination of the optically highly reflecting, relatively smooth plateau tops, and the diffuse scattering by the rough-surfaced channels.

Surface Hardness

It is well known that wear protection may be produced by surface hardening. In the case of steel this may be achieved by carburizing or nitriding. Since hardness increases with increasing fineness of grain size,[14] and the ploughing-in of wear debris into the surface can inhibit grain growth in the surface layers,[15] it follows that the ploughing-in of wear debris would be expected to result in work-hardening of the surface regions. It seemed advisable, therefore, to check whether the wear protection afforded by the phosphate coating was to any significant degree associated with the ploughing-in of the coating and an enhanced surface hardness. The results obtained clearly show that hardness was not a factor contributing to the wear protection. The hardness of satisfactorily run-in phosphated mild steel was found to be about the same as that of the original unphosphated mild steel. From this result it seems probable that very little of the coating is ploughed into the surface, and this is supported by the visual observation that the phosphate crystals are rapidly removed from the bearing surface.

Absence of Solid Lubrication

As Barwell[4] has shown, some wear protection can be initially provided by the phosphate coating which is not actuated by the presence of liquid lubricant. This protection was found to be short-lived, however, and in the present investigation it has been found that such wear protection is not apparent after the phosphated surface is run-in. The evidence shows that the phosphate crystals do not provide solid lubrication for the run-in phosphated mild steel.

It is also unlikely that the persistence of the protection is due to the presence of phosphate debris in the lubricant, as the bearing was being continually supplied with fresh, uncontaminated lubricant.

Additional evidence in support of the above conclusions is provided by the observation that a substantial deposit of phosphate crystals is not necessary to confer considerable wear protection. Phosphating for only about a quarter of the time required for fully phosphating is all that is necessary to provide appreciable wear protection, although such short phosphating times do little more than etch the surface preferentially in certain areas. The evidence obtained therefore amply justifies the assumption by Clayton[16] that the anti-scuffing properties of these surface layers cannot be attributed to the coating acting as an extreme-pressure lubricant.

Relation of Results to Wear Conditions

It should be noted that the condition of flooding lubrication, used to minimize the effect of the surrounding atmosphere, may have favoured hydrodynamic lubrication, and it is possible that this causes the hydrodynamic features to predominate in the present investigation. Nevertheless, it has been shown above that the protective action of phosphating is well exhibited under the conditions employed. Also, most of the conclusions are related to the nature of the phosphated surface prior to, and hence independent of, the wear run. Further investigations are being made under more adverse wear conditions employing much higher loads and lower speeds. Results so far obtained are in general agreement with those reported here.*

Origin of the Maximum on Wear Curves

The gain in weight of the specimens shortly after the maximum in the wear curve of Fig. 11, suggests that the bearing surfaces become relatively smooth, because of one of the following:

(i) Increased rate of oxidation of the specimen surface

(ii) Interaction of the two surfaces yields a net transfer of metal or wear debris to the specimen from the other bearing surface

(iii) Result of (i) and (ii) occurring concurrently.

The micrographs suggest that (ii) is not appreciable and (i) is therefore considered to be the more likely explanation. Further experiments are being made to test this conclusion.

* This investigation, now complete, has been summarized elsewhere (Midgley[17]). Under the more adverse wear conditions the phosphate coating contributes to wear protection but only *during* the very short running-in period.

Comparison of Iron and Iron Manganese Deposits

It was found that the two baths produced similar modifications of mild-steel surfaces, and no significant difference between the wear-protective powers endowed by the two treatments has been detected.

CONCLUSIONS

From the results obtained it is clear that under the wear conditions employed, in which the wear protection was well exhibited, the protection, both during and after running-in, was not significantly associated with change in surface composition, as suggested by Roosa, nor with enhanced surface hardness, nor phosphate crystal coalescence to form so-called phosphate glass.

All the results support the conclusion that the wear protection after running-in, and probably to a large extent during the running-in period too, arises from the modification of the surface profile produced by the treatment.

The bearing surface consists of plateaux surrounded by interconnecting channels. It has been shown that a phosphated surface can be successfully lubricated with a much lower viscosity lubricant than an untreated surface, and as reported by Martz[11] many examples are known, including phosphated steel, in which increasing the surface roughness increases the scuffing load by up to 100%. The conclusion is that the surface channels trap the lubricant and thus resist the tendency to squeeze the lubricant from between the bearing surfaces. Horizontal drag on the partially trapped lubricant gives rise to pressure wedges sufficient to support the load and thereby an adequate supply of lubricant to the interface is ensured. The discontinuities in the surface will also prevent wear becoming progressive and provide the necessary outlet for wear debris which might otherwise cause wear (cf. Finch[18]). The bearing surface is reduced by about 50% by the process, and this must facilitate the rapid mating of the surfaces without the removal of the lubricant, for the reason given above, so that rapid wear and seizure are avoided.

Acknowledgments

The author wishes to express his sincere appreciation to Dr. H. Wilman for his constant encouragement and advice; Dr. D. P. D. Webb and Mr. M. R. Piggott for help and criticism; Mr. E. S. Brett and the staff of the workshop for their continual support; and the Metallurgy Department of Imperial College for the use of the microhardness tester. He also wishes to thank Dr. F. T. Barwell and the staff of the Lubrication and Wear Division of the D.S.I.R. Mechanical Engineering Research Laboratory, Glasgow, for their generous help in making available apparatus and for many useful discussions; Mr. A. Jobbins of the Geological Museum Laboratories, South Kensington, for the determination of the optical constants of the phosphate crystals; I.C.I. Paints Division, The Pyrene Co. Ltd., and The Walterisation Co. Ltd., for the supply of phosphating solutions and for discussions; and Shell Mex and B.P. Co. Ltd. for the supply of the premium-grade undyed kerosene.

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A Note on the Furnace Cracking of an Austenitic Stainless Steel

By F. A. Hodierne, B.Sc., A.I.M.

SYNOPSIS

Cold-drawn tubes in an 18/10 austenitic stainless steel containing niobium cracked transversely on heating for interpass softening. This cracking was reproduced experimentally in a laboratory test at temperatures between 650° and 950° C, and appears to be associated with the precipitation of intergranular carbides in a steel with high internal stress. Cracking has been avoided in practice by precipitating the carbides at 850° C before cold-drawing the tubes. 1282

TUBES 5½ in. outside diameter by ⅝ in. thick in an 18/10 austenitic stainless steel containing niobium were extruded before cold-drawing. Extrusion had taken place at about 1260° C, after which the tubes had been air-cooled. The tubes were given three light cold-drawing passes, followed by heating to 1100° C to soften them for further cold-drawing. Severe transverse cracking was consistently obtained (Fig. 1).

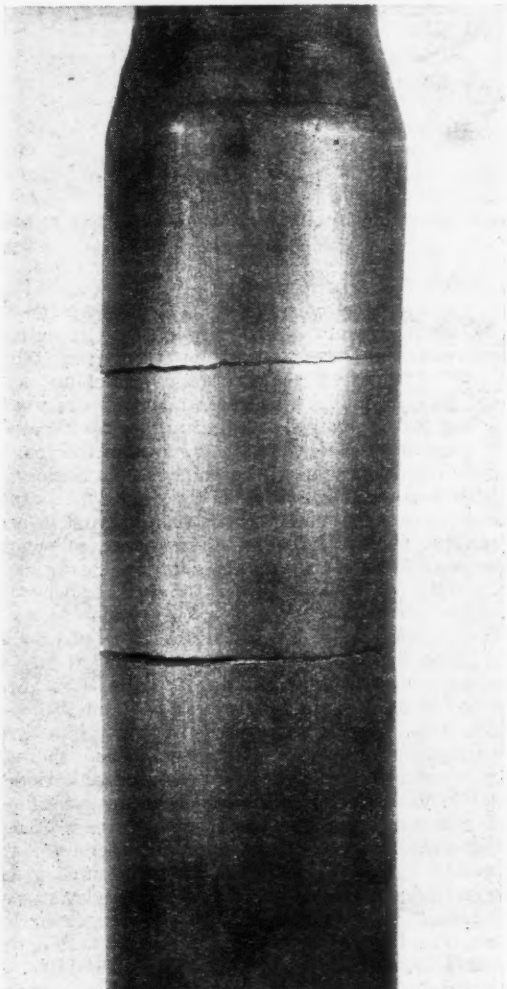

Fig. 1—Tube showing transverse cracks developed during heating

There was no evidence that the cracks were associated with any defects in the tubes, and several casts of steel were involved; careful inspection failed to reveal any trace of cracking prior to heat-treatment. It was known that light drawing passes of the type given result in high values of internal stress,* particularly in the longitudinal direction, but heavier passes could not be given because of power limitations on the drawbench. Residual-stress determinations revealed a hoop bending stress of 16 tons/in² and a longitudinal bending stress of 25 tons/in².

Attempts were made to stress-relieve some of the drawn tubes by heating at 750° C for 1 h before the interpass softening treatment at 1100° C, but transverse cracking occurred at the lower temperature. At this stage experiments were started in an attempt to reproduce the cracking in the laboratory and determine the cause.

PRODUCTION OF EXPERIMENTAL TUBES

A tube, 5⅛ in. outside diameter by 9/16 in. thick, was selected which had cracked at one end during heat-treatment but not at the other. The composition of the steel was C, 0·11%; Si, 0·72%; S, 0·009%; P, 0·038%; Mn, 1·47%; Cr, 18·48%; Ni, 10·32%; Nb, 1·18%.

From the sound end of the tube two 18-in. lengths were cut and marked 1 and 2. Tube 1 was heated to 1260° C for 1 h and water-quenched. This treatment dissolved a considerable amount of carbide, the structure showing some carbide stringers but no other carbide particles. Tube 2 was heated to 850° C for 30 min and air-cooled, followed by heating to 1050° C for 30 min and water-quenching. This produced a microstructure in which most of the carbide was out of solution, in the form of coarse longitudinal stringers and small particles randomly dispersed throughout the austenite grains. Both tubes were given three cold-drawing passes of 7½%,

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* D. K. Crampton: *Trans. Amer. Inst. Min. Met. Eng.*, 1930, vol. 89, pp. 233–248.

W. J. Knights, Thesis, University of London, 1951.

Table I

RESULTS OF STRESS-CRACKING EXPERIMENTS

Time to reach furnace temperature, 5–8 min

Tube No.	Specimen No.	Temperature, °C	Cracking Time
1	1A, 1B, 1C	750	20 min
1	1D, 1E	750	25 min
1	1F	650	75 min
1	1G	850	25 min
1	1H	950	90 min*
1	1J	1050	1 h (not cracked)
1	1K, 1L†	1050	5 min†
1	1M, 1N	1150	1 h (not cracked)
2	2A, 2B	650	3 h (not cracked)
2	2C, 2D	750	7 h (not cracked)
2	2E	850	2 h (not cracked)
2	2F	950	1 h (not cracked)
2	2G	1050	1 h (not cracked)

* Cracking was not observed in the furnace but slight cracking was found on removal.

† Specimens 1K and 1L had not attained the furnace temperature when they cracked.

7½%, and 5½% reduction in area respectively to the following sizes:

1st pass to 5·00 in. o.d. by 0·525 in. thick.
2nd pass to 4·937 in. o.d. by 0·500 in. thick.
3rd pass to 4·875 in. o.d. by 0·475 in. thick.

These passes are of the same order as those given to the tubes that cracked in production.

STRESS-CRACKING EXPERIMENTS

Rings 1 in. wide were cut from each tube and cut diametrically in half. The possibility of surface treatments such as pickling and lubrication affecting the results was eliminated by grinding all over the surface of each specimen. These half rings were then stressed to just above the yield point (about 25 tons/in²) at room temperature by means of a ½-in. stainless-steel bolt (Fig. 2). This was achieved by noting the strain required to produce a measurable permanent set. The stressed specimens were then heated at different temperatures. Cracking was found to occur only in tube 1 at temperatures between 650° and 950° C (Table I). Since the stresses imposed were circumferential, the cracking was in the longitudinal direction (Fig. 2), but microscopic examination showed the cracks to be of the same type as the transverse cracks observed in the original tubes (Fig. 3). The cracks were intergranular, following films of carbides in the grain boundaries.

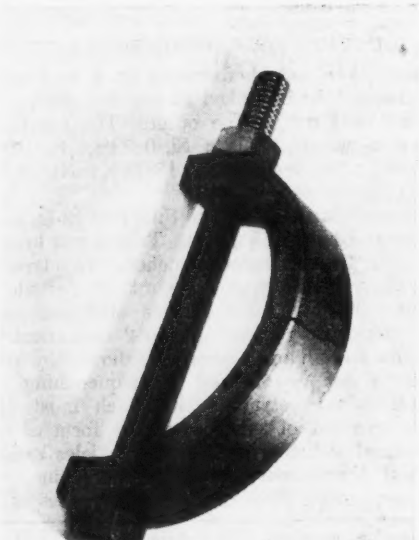

Fig. 2—Stressed specimen (No. 1D) cracked after heating at 750° C

Fig. 3—Section of small crack in specimen 1D; etched in oxalic acid × 750

DISCUSSION OF RESULTS

Tubes 1 and 2 differed in that the steel of tube 2 had little carbide in solution while the steel of tube 1 was supersaturated with dissolved carbide. Cracking had occurred in tube 1 between 650° and 950° C, which is the temperature range in which carbides are precipitated, and microscopic examination showed that the cracks followed the intergranular carbide. It is significant that cracking can occur an appreciable time after the specimen has reached the furnace temperature. It seems reasonable, therefore, to associate the cracking with the precipitation of intergranular carbide while the steel is under stress, the carbide either increasing the local stresses at the grain boundaries or lowering the cohesive strength. Cracking at furnace temperatures of 1050–1100° C is attributed to the fact that the steel must pass through the carbide precipitation temperatures during heating. With thick tubes the heating is necessarily

slow and the time at these temperatures may be adequate for cracking to occur (Table I, tests 1K and 1L).

On the basis of this possible explanation, a procedure was devised to avoid cracking of the tubes and this has been successful for over two years. All large tubes in this steel are heated at 850° C for 1 h before each cold-drawing operation, this treatment following the usual interpass softening at 1050–1100° C.

No cracking of a similar nature has been observed in production on tubes of other steels, and even on this steel the necessary conditions only occur with one particular size range. Laboratory tests have shown that a similar effect is possible in a titanium-stabilized austenitic steel, but the conditions of stress and structure necessary for cracking are very critical and the effect is difficult to reproduce.

Acknowledgments

The author would like to thank Dr. J. W. Jenkin and Tube Investments, Ltd. for permission to publish this note.

Effect of Alternate Corrosion and Abrasion on Some Ferrous Metals

By J. Dearden, M.Sc., F.I.M., A.M.I.Mech.E., and J. D. Swindale, B.Sc.

SYNOPSIS

The resistances of 11 ferrous metals to atmospheric corrosion, to abrasion, and to certain combinations of both have been compared. Resistance to corrosion was reduced by abrading the rust, and increasing frequency of abrasion increased the corrosion rate, except for grey cast iron which behaved differently from the other materials. The slow-rusting qualities of Cor-Ten steel were not developed under frequent abrasion.

Resistance to abrasion alone was found to be related to a defined equivalent carbon content of the steels tested rather than to their hardness. There was a marked increase in the loss per abrasion of all materials when corrosion alternated with abrasion.

Three white cast irons showed exceptional resistance to corrosion, even when combined with abrasion, and to abrasion alone. Grey cast iron corroded similarly to the unalloyed steels, but with increasing frequency of abrasion its position rose in the order of merit; its resistance to abrasion alone was good.

A selected bibliography on British corrosion tests on iron and steel panels and products, and in various environments, has been included for reference. 1229

COMPARISONS OF RESISTANCE to atmospheric corrosion are usually made by exposing weighed panels of various materials for periods of one to five years, after which the panels are cleaned and re-weighed. In the case of ferrous materials there is a reduction in the corrosion rate as the exposure continues, especially during the first year, owing to the partial protection provided by the rust, and the slow-rusting low-alloy steels are believed to owe their corrosion resistance largely, if not wholly, to the formation of tough, coherent layers of rust.

There are, however, many situations where occasional abrasion, rolling, hammering, or other surface pressures makes it impracticable to paint, lubricate, or otherwise protect exposed surfaces of iron and steel. Under such conditions, at least some of the rust is removed periodically, so that it does not develop its normal protective qualities, and the corrosion of such surfaces is likely to be much more rapid than that shown by undisturbed panels.

This reduction in resistance to corrosion is supplementary to the already reduced resistance of a corroded surface to abrasion, rolling, hammering, etc. Thus there are grounds for thinking that the relative resistances of various ferrous materials to corrosion or abrasion may be very different in circumstances where corrosion and abrasion are alternated or combined.

There is no lack of examples of such circumstances to be found in the equipment used in civil engineering, mining, quarrying, agriculture, transport, and other outdoor activities. Typical examples are hoppers, chutes, and wagons used for the storage, handling, or transport of coal, coke, stone, or other minerals, but there are also the innumerable unlubricated pins, links, shackles, hooks, etc. in exposed places, where slight relative movement abrades and removes the rust from the contacting surfaces.

The wear of steel rails is largely a process of combined corrosion and wear, in which the corrosion is accelerated by the partial removal of the rust, and the wear is accelerated by the corrosion of the running surface. The underside of the rail is liable to galling where it is in contact with the chair or baseplate and slight relative movement disturbs the rust; a similar

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The authors are with the British Railways Research Department.

Table I
COMPOSITION OF MATERIALS FOR TESTING

Material	Thickness, in.	Analysis, %								Diamond Pyramid Hardness No.
		C	Si	Mn	S	P	Ni	Cr	Cu	
Panel steel	$\frac{1}{16}$	0·07	Tr.	0·29	0·027	0·008	0·05	0·10	0·11	97
Cor-Ten	$\frac{3}{32}$	0·12	0·54	0·44	0·050	0·10	...	0·76	0·37	170
Spring steel (normalized)	$\frac{3}{32}$	0·50	0·14	0·60	0·043	0·032	0·13	0·09	...	200
Spring steel (hardened)	$\frac{3}{32}$	0·53	0·08	0·76	0·036	0·032	...	...	...	720
Ni-Hard	$\frac{1}{8}$	2·60	0·90	0·45	0·10	0·56	4·5	1·5	...	590
Hadfield's manganese steel	$\frac{3}{32}-\frac{3}{16}$	(1·00)		(12·00)			...	...	...	230
White iron containing Cr	$\frac{1}{8}$	2·40	1·00	0·35	0·10	0·06	...	0·4	...	470
Grey cast iron	$\frac{1}{8}$	3·10	1·30	0·60	0·20	0·75	...	...	...	247
Rail steel	$\frac{3}{32}$	0·55	0·25	0·70	0·05	0·05	...	...	...	274
Mild steel	$\frac{3}{32}$	0·16	Tr.	0·49	...	...	...	0·12	0·176	145
Chill cast iron	$\frac{1}{8}$	3·10	1·30	0·60	0·20	0·75	...	...	...	670

action occurs where the edges of fishplates make contact with the rails.

In view of the innumerable cases where combined or alternating wear and corrosion determine the life of a component, it was decided to make tests on a wide variety of ferrous materials under certain standard conditions ranging between the extremes of corrosion only and abrasion only. The materials were tested in the form of flat panels $3\frac{1}{2}$ in. sq. and $\frac{1}{16}-\frac{1}{8}$ in. thick; particulars of their condition, composition, and hardness are given in Table I.

EXPERIMENTAL PROCEDURE

To obtain corrosive–abrasive conditions the panels were exposed in an industrial atmosphere outside the British Railways Research Laboratory at Derby until a 'control' panel had achieved a standard increase in weight due to corrosion. They were then brought indoors and subjected to a controlled abrading with emery cloth, using a linishing machine. The panels were hung on a line about 10 ft from the ground and faced approximately south-west; they were exposed with one face alternately to the S.W. and then to the N.E. to equalize the effects of the prevailing winds.

Although exposure of the specimens in a weatherometer would have given quicker results and more precise control, it was considered that such accelerated corrosion would not necessarily reproduce the effects of natural rusting in an industrial atmosphere; the latter procedure was therefore adopted.

The duration of each exposure to the corroding conditions was decided by a control specimen of panel steel. This was linished before being hung out each time, to remove completely all traces of any previous rusting and to ensure that each exposure of the control panel started under exactly reproducible conditions. One standard exposure period was considered complete when this cleaned control panel had gained 0·175 g due to corrosion, this figure representing the average gain in weight per week, determined from previous work on the corrosion of panel steel outside the laboratory. This period is referred to as a 'standard corrosion week.' It was very rarely a seven-day week, and ranged from two days to three weeks, according to the prevailing weather. Half a 'standard corrosion week' was determined by the period of time in which the control panel gained in weight by half of 0·175 g. For two 'standard corrosion weeks,' two control panels were exposed consecutively until their combined gain in weight was twice 0·175 g.

Owing to the vagaries of the weather, it was found to be impracticable to make each corrosion period coincide with a gain in weight of precisely 0·175 g on the control panel. However, any small deficiency of exposure in one period was compensated by a corresponding excess in the next. The validity of this procedure was checked experimentally over the range involved.

Removal of the corrosion products was achieved by using a fine grit belt on a linishing machine, the belt having been previously worn or 'run in' to reduce its initially high abrasiveness. The width of the belt decided the dimensions of the panels, these being made sufficiently smaller than the belt to ensure even abrasion. The belt was not used for any purpose other than the experiment. The pressure on the panels during linishing was fixed at 0·65 lb/in² by the use of a suitable weight. Abrading was carried out for 10 s in each of two directions at right-angles to each another for each face of the panel, making a total time of 40 s for each panel. The time of 10 s was taken with power on the motor, and the over-run was completed before the panels were removed. The time of 40 s was chosen as that necessary just to remove the loose rust from both sides of panel steel after an exposure of 4 'standard corrosion weeks'; for shorter exposures, portions of the specimens would be reduced to bare metal during the standard abrasion. The order of linishing was alternated to allow for the possibility of the belt wearing smoother as the experiment proceeded, though the belt appeared to be as capable of removing rust at the end of the experiment as when it was first used.

There are, of course, many different forms of abrasion in practice; the above form was chosen because

it seemed the only practical method of applying a controllable degree of abrasion to specimens suitable for exposure to corrosion.

Before commencing the experiment, each panel was thoroughly abraded in two directions at right-angles on the linishing machine to ensure that its surfaces were worn so as to be in conformity with the abrasive belt.

Panels were weighed at the start of the experiment and, after a convenient number of corrosion–abrasion cycles, the loss of weight gave a measure of the resistance of the material to the conditions imposed upon it.

The experiment was conducted in two sections, the first being mainly exploratory and designed to check the reproducibility of results, and the second part to extend the ratio of corrosive to abrasive conditions. In all these experiments the amount of abrasion given was kept constant. To check the reproducibility of results, the first part of the experiment was duplicated, two panels of each material being hung out-of-doors and given the same treatment. Exposures were made in the open air for the ' standard week ' between abrasions, and abrasion of the ' no corrosion ' specimens was made concurrently.

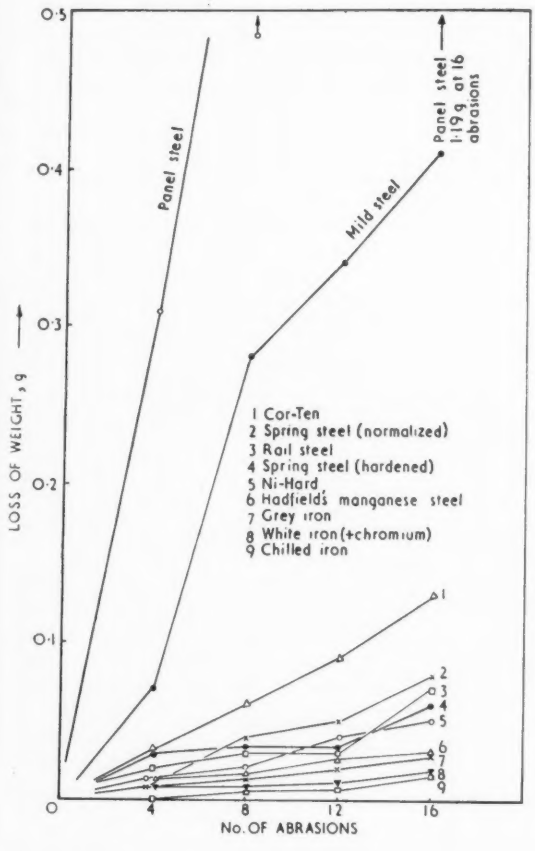

Fig. 1—Loss of weight to abrasion only

Table II

DIFFERENCE IN LOSS OF WEIGHT BETWEEN TWO PANELS OF THE SAME MATERIAL

After 25 cycles of one ' standard corrosion week ' between abrasions

Material	Difference between two panels, %
Panel steel	6
Cor-Ten	4½
Spring steel (normalized)	4
Spring steel (hardened)	16
Rail steel	2
Mild steel	9
Ni-Hard	10
Hadfield's manganese steel	0
White cast iron and chromium	8
Grey cast iron	6
Chill cast iron	8

From this first part of the experiment it was found that two panels of the same material behaved in very similar ways, even where differences of thickness of 100% were present, and that the result from one panel only could be safely accepted as being sufficiently accurate for an investigation which was concerned more with the comparative order of merit of different materials than with the absolute losses under certain combinations of abrasion and corrosion. The differences found between the pairs of panels are shown in Table II.

Correlation between those panels subjected to abrasion only was equally reproducible, though in this experiment the age of the linishing belt did affect the amount of material removed. This was most noticeable with the harder materials, while the three softest (panel steel, mild steel, and Cor-Ten) showed little effect of belt wear.

EXPERIMENTAL RESULTS

On the completion of these preliminary tests of pairs of panels exposed for one ' standard corrosion week,' single panels of each material were exposed for periods of ½, 1, 2, 4, and 8 ' standard weeks ' between abrasions, and three panels of each were exposed continuously for one year without any abrasion.

Before any measurements were made at the start of a series under new conditions, a ' running-in ' period of five cycles was allowed for the surfaces of the test panels to reach equilibrium under the conditions of the test. This was considered necessary because of the differing amounts of rust remaining on the panels after a standard abrasion following varying amounts of corrosion. The amount of abrasion was not varied, since a more severe abrasion would, on panel steel, remove more uncorroded metal and not additional rust. A less severe abrasion would have been difficult to control owing to the small time intervals involved.

Abrasion without Corrosion

The results of abrasion alone are given in Fig. 1. These represent the average values obtained from two

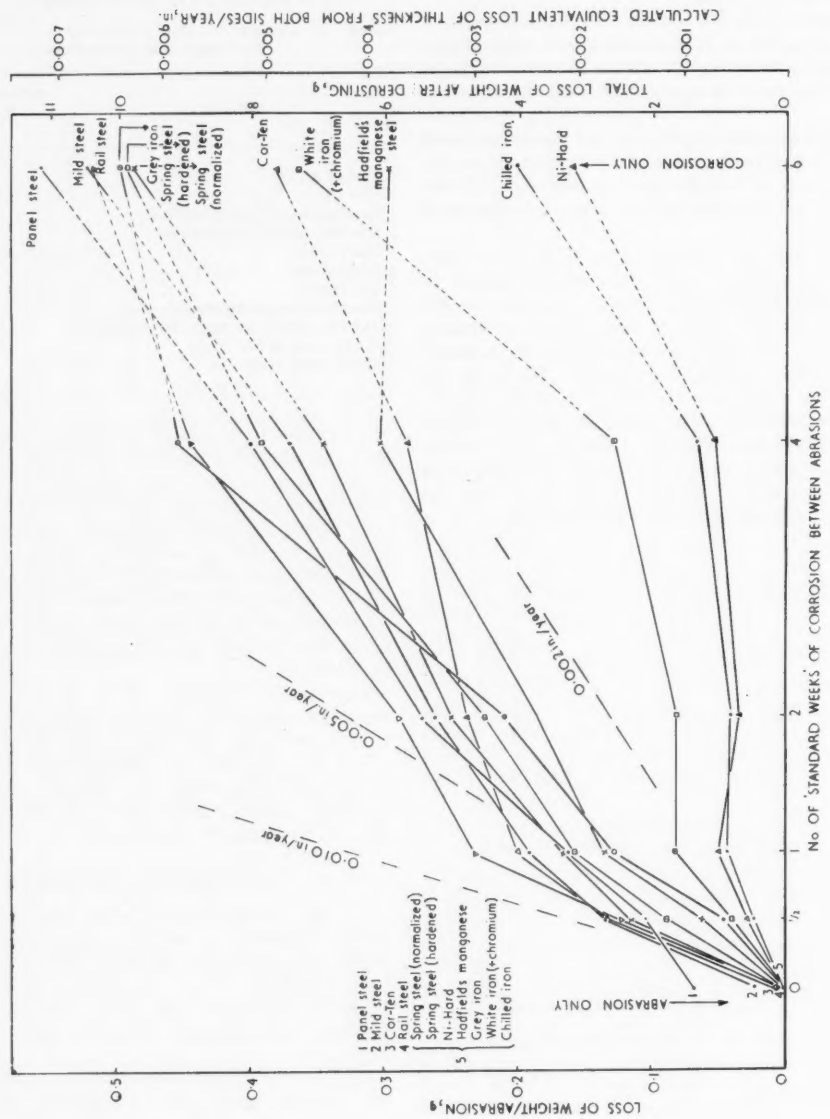

Fig. 2—Loss of weight per abrasion for varying amounts of corrosion between abrasions

specimens for each material weighed after every four abrasions. Owing to the very wide range of values observed, it was not possible to plot all the points on the graph.

Alternate Corrosion and Abrasion

The duration of each series of tests can be seen from Table III.

The cumulative losses in weight after the various corrosion–abrasion cycles were plotted on a basis of cumulative gain in weight of the control panel due to corrosion. These graphs proved to be roughly straight lines, showing that steady conditions had been achieved; these elementary graphs have been omitted for simplicity, but the information derived from them has been used in the construction of the more comprehensive graphs in Figs. 2 and 3.

Each point in these figures represents the average loss in weight over 6–25 cycles (*see* Table III). Each vertical group of points represents a separate experiment in which each specimen received exactly the same treatment over the same period of time. The order of the points in each group is the inverse of the order of merit in resistance to the conditions applied to that group.

The loss per abrasion when varying amounts of corrosion were permitted between abrasions is recorded in graphical form in Fig. 2. This shows that the loss increased as more corrosion occurred, though different materials were affected to varying degrees, as is revealed by the slopes of the lines joining the points.

The results obtained from allowing corrosion for eight ' standard weeks ' to occur between abrasions have not been included; these panels corroded to such an extent that the abrasion did not remove all the loose rust, and a gain in weight instead of a loss was experienced owing to the retention of rust. It was visually apparent that only a proportion of the rust had been removed, and it was probable that the remaining rust layer of a distinct thickness on these panels would behave in a different manner from that on the panels where some bare metal was exposed.

The radial broken lines in Fig. 2 indicate how various corrosion rates would fit on to the diagram, e.g. rail steel with one ' standard week ' of corrosion between abrasions was wearing at about 0·007 in./year.

The left-hand ordinate of Fig. 2 is related to abrasions, and the time between abrasions varies for the different conditions. To relate the loss of weight to time, the information has been replotted as loss of weight per ' standard corrosion week,' and this is given in Fig. 3. The horizontal scale is an arbitrary one, and the loss of weight due to abrasion in the absence of corrosion is shown at the left-hand side to indicate the order of merit under these conditions. Similarly the total loss of weight due to corrosion alone (divided by 52) of the panels exposed continuously for one year is recorded at the right-hand side of the diagram.

Table III
DURATION OF TESTS

Exposure Periods, ' standard weeks '	Number of Corrosion–Abrasion Cycles Applied	Duration of Test, ' standard weeks '
½	25	12½
1	25	25
2	12	24
4	6	24
8	3	24

Table IV
LOSS OF WEIGHT RELATED TO HARDNESS AND EQUIVALENT CARBON

Type of Steel	Loss of Weight after 16 Abrasions	Diamond Pyramid Hardness No., H_D	Carbon Equivalent, $C+\frac{Mn}{3}+\frac{Cr}{3}$
Panel	1·19	97	0·17
Mild	0·41	145	0·32
Cor-Ten	0·13	170	0·52
Spring (normalized)	0·08	200	0·77
Rail	0·07	274	0·78
Spring (hardened)	0·06	720	0·78

Corrosion without Abrasion

At the right-hand side of Fig. 2, the loss of weight after one year's exposure is shown, and also the calculated equivalent (for steel) loss of thickness from both sides. These panels were not subjected to any abrasion, the products of corrosion being removed chemically by treating in Clarke's solution, which removed rust without attacking the steel underneath. The scales for this last item bear no relation to the horizontal or vertical scales for the rest of the diagram, but the data are included to give the whole information on one diagram.

DISCUSSION OF RESULTS

Abrasion without Corrosion (Fig. 1)

The loss due to abrasion alone is related approximately to hardness and carbon equivalent for the steels that have been examined, as is shown in Table IV. The carbon equivalent is calculated from a simple formula, $C+\frac{Mn}{3}+\frac{Cr}{3}$, which combines the effect of these three elements in a single figure. It is applicable only to steel in the as-rolled or normalized conditions and is related to the tensile strength; it is not a measure of hardenability.

This tabulation suggests that the equivalent carbon content is of greater importance than hardness in controlling the resistance to abrasion of this type; the higher the equivalent carbon is, the greater is the resistance to wear. The hardness of the material does influence to some extent the resistance to abrasion, but the raising of the hardness of spring steel from 200 H_D to 720 H_D reduces the wear only in the ratio of 8 : 6; this does not approach the reduction to be obtained by increasing the carbon content.

Alternate Corrosion and Abrasion (Figs. 2 and 3)

When considering Figs. 2 and 3 it is important to regard them as diagrams of order of merit of the materials under different circumstances, and not as normal graphs. This method of presentation of the results has been chosen because it incorporates all

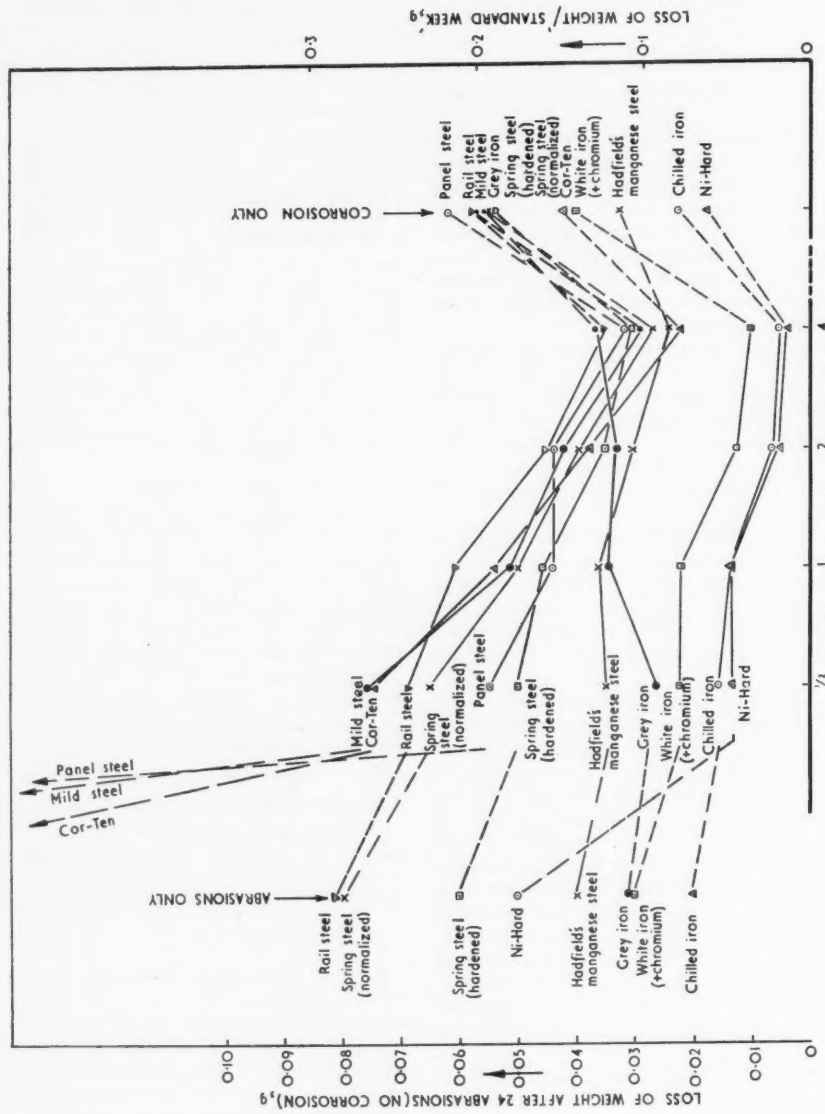

Fig. 3—Loss of Weight per 'Standard Week' for Varying Amounts of Corrosion between Abrasions

Table V

ORDERS OF MERIT FOR RESISTANCE TO ABRASION AND/OR CORROSION

Abrasion Only No Corrosion	Number of 'Standard Corrosion Weeks' between Abrasions				One Year's Corrosion No Abrasion
	½	1	2	4	
Chilled iron	Ni-Hard	Ni-Hard	Ni-Hard	Ni-Hard	Ni-Hard
White iron + Cr	Chilled iron	Chilled iron	Chilled iron	Chilled iron	Chilled iron
Grey iron	White iron + Cr	White iron + Cr	White iron + Cr	White iron + Cr	Manganese steel
Manganese steel	Grey iron	Grey iron	Manganese steel	Cor-Ten	White iron + Cr
				Manganese steel	Cor-Ten
Ni-Hard	Manganese steel	Manganese steel	Grey iron	Spring steel (normalized)	Spring steel (normalized)
				Mild steel	Spring steel (hardened)
					Grey iron
Spring steel (hardened)	Spring steel (hardened)	Panel steel	Spring steel (hardened)	Spring steel (hardened)	Rail steel
	Panel steel	Spring steel (hardened)		Panel steel	Mild steel
Rail steel	Spring steel	Spring steel	Cor-Ten		
Spring steel (normalized)	(normalized)	(normalized)	Spring steel (normalized)	Rail steel	Panel steel
	Rail steel	Mild steel		Grey iron	
		Cor-Ten	Mild steel		
Cor-Ten	Cor-Ten	Rail steel	Panel steel	...	...
Mild steel	Mild steel		Rail steel		
Panel steel	...	...	...	...	...
	...	...	...	...	...

the materials and all the test conditions in each diagram and therefore simplifies their comparison.

The general slope of the lines in Fig. 2 shows increasing losses per abrasion with longer periods of corrosion between the abrasions. With the exception of panel steel and mild steel, the lines are roughly radial from zero up to one 'standard week'; this means that the rate of loss of weight was then constant for each material. For periods of corrosion longer than one 'standard week,' the slope of the lines (excepting grey cast iron) is less, indicating the protective influence of the rust which accumulated during the longer exposures.

In Fig. 3 the general slope of the lines shows decreasing losses in weight per 'standard week' with longer periods of corrosion between abrasions. This is essentially because there were fewer abrasions per 'standard week' with longer periods of corrosion.

Corrosion without Abrasion

The results are shown at the right-hand sides of Figs. 2 and 3. The range in values is very wide owing to the inclusion of ferrous materials not usually exposed simultaneously in a corrosion test. This range is about $3\frac{1}{2}$ to 1, but with increasing amounts of abrasion it expands until it is 60 to 1 for abrasion only.

CONCLUSIONS

General

The resistances of 11 ferrous metals to atmospheric corrosion, to abrasion, and to varying combinations of both have been compared and the results are summarized in order of merit in Table V. The changes in the order of merit with varying conditions are discussed later. With the exception of grey cast iron, all the materials showed an increased rate of corrosion with increasing frequency of abrasion.

Figure 1 shows the relative resistance of these materials to abrasion alone. For the few steels tested, the effect of equivalent carbon content on their resistance to abrasion was more marked than that of hardness; small increases in equivalent carbon caused large reductions in the loss due to abrasion.

Figure 2 shows the marked increase in loss per abrasion when corrosion was introduced, but the increase varied in different materials; the rate of increase fell off as the corrosion period increased.

Under pure abrasion the ratio of the losses of the most and least resistant materials was of the order of 60 : 1; with corrosion alone or combined with abrasion, this ratio was reduced to between 10 : 1 and 3 : 1. This feature illustrates the levelling effect of corrosion on the resistance to abrasion.

The three white cast irons ('Ni-Hard,' 'White Iron plus Chromium,' and 'Chill Cast Iron') all showed exceptional resistance to abrasion and corrosion or both combined. The amount of corrosion between abrasions had very little effect on the loss per abrasion compared with the steels (*see* Fig. 2). The white cast irons also showed considerably greater resistance to corrosion without abrasion.

Cor-Ten

The slow-rusting qualities of this steel were not allowed to become fully apparent except in the absence of abrasion. The more frequently it was abraded, the less effective was the protection provided by the rust, and, when the rust was removed once or twice per 'standard corrosion week,' Cor-Ten corroded similarly to mild steel.

Grey Cast Iron

In the absence of abrasion, this material corroded similarly to the unalloyed steels but, with increasing frequency of abrasion, it behaved differently from all the other materials and exhibited abnormal resistance to abrasion, with or without slight corrosion. Its

position in the order of merit thus rose from eighth for corrosion only to third for abrasion only. None of the other materials had its resistance to abrasion so much reduced by corrosion. No explanation is offered for this anomalous behaviour.

Chill Cast Iron

Although cast from the same ladle of metal as the grey cast iron, this material behaved very differently. Its resistance to corrosion alone was about $2\frac{1}{2}$ times that of the grey iron, and the frequency of abrasion had relatively little effect on its resistance. It had the greatest resistance to abrasion alone, but, unlike the grey iron, this resistance was not seriously reduced by corrosion.

Ni-Hard

This material was the most resistant to corrosion alone, probably on account of its high nickel and chromium contents. With alternate corrosion and abrasion, it behaved very similarly to chilled iron and was relatively insensitive to the frequency of abrasion. Its resistance to abrasion alone was much inferior to that of the other two white irons.

White Iron Containing Chromium

This material proved slightly inferior to the other two white irons under all conditions except pure abrasion, when Ni-Hard was the inferior of the three. With corrosion alone, it was much worse than the other two, being about the same as Cor-Ten.

Spring Steel (normalized and hardened)

There was no difference in the corrosion rates of this material in either condition, but with increasing frequency of abrasion, the hardened became superior to the normalized steel. However, the superiority was not very marked, and under pure abrasion amounted to only a 25% reduction in loss for an increase in hardness from 200 H_D to 720 H_D. Much greater resistance to abrasion was shown by softer materials, such as the white irons, grey iron, and Hadfield's manganese steel.

Rail Steel

This steel corroded similarly to the other unalloyed steels, but, with increasing frequency of abrasion, it became the lowest in the order of merit when abraded every one or two weeks. Under abrasion alone, its resistance was superior to Cor-Ten, mild, and panel steels, but the same as normalized spring steel of the same equivalent carbon content but lower hardness. After grey cast iron, rail steel was the material whose resistance to abrasion was most reduced by corrosion.

Hadfield's Manganese Steel

This was the steel most resistant to corrosion alone, and was also the steel least affected by increasing frequency of abrasion. It did not resist abrasion alone as well as did grey iron, chill cast iron, or white iron containing chromium. Its well known abrasion resistance is developed only when it is subjected to work-hardening by impact, and this feature was absent in these tests.

Panel Steel

This material behaved similarly to mild steel except under pure abrasion when it lost three times as much, being the softest and lowest in equivalent carbon content of all the materials tested.

Mild Steel

Having regard to its hardness and composition in comparison with the other materials, this steel behaved as would be expected.

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A Pneumatic Level Indicator for the Continuous Casting Process

By A. G. Grimshaw and B. O. Smith, M.Sc., A.Inst.P.

SYNOPSIS

The pneumatic gauging principle is applied to a level indicator suitable for the continuous casting process for steel. Indication is obtained over a 6-in. length of the mould with an accuracy of better than $\frac{1}{2}$ in. The level indicator provides an electrical output signal which could be used to control either the rate of pouring from the tundish, or the rate of withdrawal of the ingot. 1375

Introduction

IN THE CONTINUOUS CASTING process, it is necessary to maintain the level of the molten steel to within fairly close limits; otherwise there is a danger of the metal overflowing or, if the level falls too low, the wall of solidified steel is unsufficient to retain the molten core of metal as the ingot emerges from the mould. Although there are already several methods of indicating metal level, they suffer from certain disadvantages, and it was decided to investigate the possibility of using a pneumatic gauging system.

The basic principle of a pneumatic gauging system employs a stream of gas, usually air, which passes through two restrictions R_1 and R_2. One restriction R_1 is fixed in size, while the effective dimension of R_2 is made to vary in some manner with changes in the variable to be measured. Then, since the gas flow is common to both R_1 and R_2, the ratio of the pressure differentials across R_1 and R_2 is a measure of

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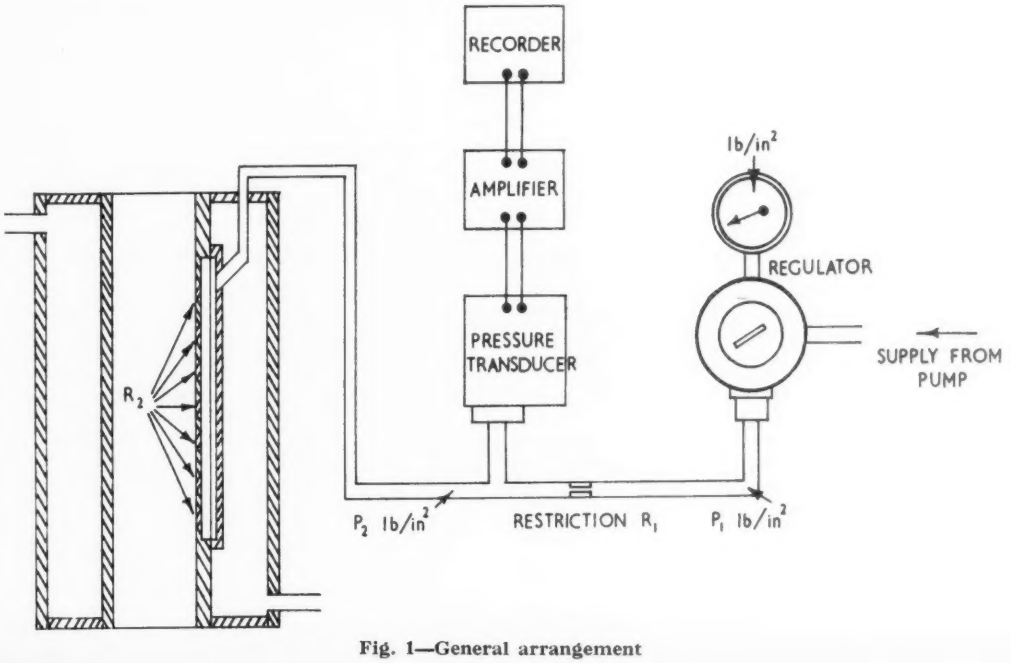

Fig. 1—General arrangement

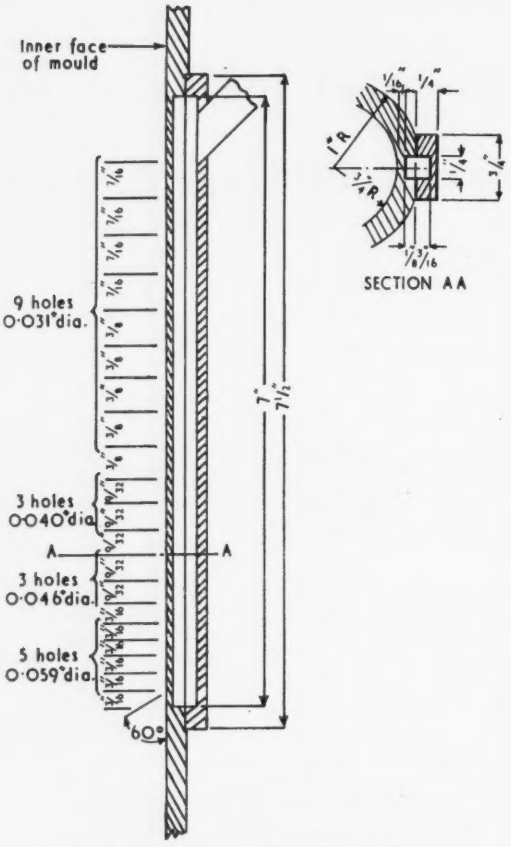

Fig. 2—Mechanical details of R_2

the ratio of their effective dimensions, which can be related to the measured variable. Alternatively, if the system is supplied from a constant pressure source at P_1 lb/in² above atmosphere, and if the downstream side of R_2 vents to atmosphere, then the pressure P_2 existing in the channel connecting R_1 and R_2 will be a function of the measured variable. This latter system has been adopted in the level indicator described in this paper. If the changes in the pressure P_2 are converted to an electrical signal, this signal can be used to control either the flow of metal from the tundish to the mould, or the ingot withdrawal rate.

GENERAL DESCRIPTION OF INSTRUMENT

In the form developed for the measurement of liquid metal level in a vertical mould, the variable restriction R_2 comprises a series of small holes drilled through the mould wall, as shown in Fig. 1. On one side, these holes are exposed to the metal being cast; on the other, they are connected to a common channel or pipe running up the chilled face of the mould and away to the restriction R_1 and the pressure source. As the level of the liquid metal changes, a differing number of holes will be covered. Hence, the effective restriction R_2, comprising those holes which are uncovered, is related to the metal level.

The remainder of the apparatus consists of a wide-bore pipe leading to a pressure indicator (or transducer) and the restriction R_1 which is a plain narrow-bore tube. In turn, R_1 is connected via a pressure regulator to a pressure source, which can be either a small compressor or a gas cylinder. In the form of the apparatus developed, a pressure transducer converts the pressure in the section between R_1 and R_2 into an electrical signal, which, after amplification, is displayed on a pen recorder.

DESIGN DETAILS

Variable Restriction R_2

Indication of variation in level over about 6 in. is required, so that the series of holes must cover at least this length. Upper and lower limits of hole diameters are limited by two factors: experience in this and other work on the continuous casting process has shown that holes less than 0·020 in. in diameter are liable to become blocked by dirt, etc., and are difficult to clear, while, for holes larger than about 0·080 in. in diameter, there is a serious risk that the newly cast material may flow into them.

It will be apparent that, as the metal level changes, the pressure P_2 will change in definite steps as each hole is covered or uncovered in turn. Hence, to obtain a sensitive indication, a large number of closely spaced holes is desired. However, if the holes are uniform in diameter and spacing, a given level change, closing say five holes at the lower portion of the mould, will produce a negligible effect compared with a similar change higher in the mould, closing the last five holes. To minimize this effect, therefore, and to produce a more linear calibration, the holes should be closely spaced and of a larger diameter at the bottom of the mould, and widely spaced and of a smaller diameter at the top. The optimum diameter and spacing of the holes in the apparatus developed range from 0·059 in. in diameter at $\frac{3}{16}$ in. spacing to 0·031 in. in diameter at $\frac{7}{16}$ in. spacing. In addition, the holes are inclined at 60° to the vertical (with the lower end at the inner face of the mould) to minimize the risk of blockage from metal splash. The holes connect to a channel formed partly in the chilled side of the mould wall and partly in a cover plate as shown in section AA of Fig. 2.

These holes, 20 in number, are spaced in a single line parallel to the axis of the casting mould, giving 20 steps in level indication over a 6-in. height. If increased discrimination is desired, a larger number of

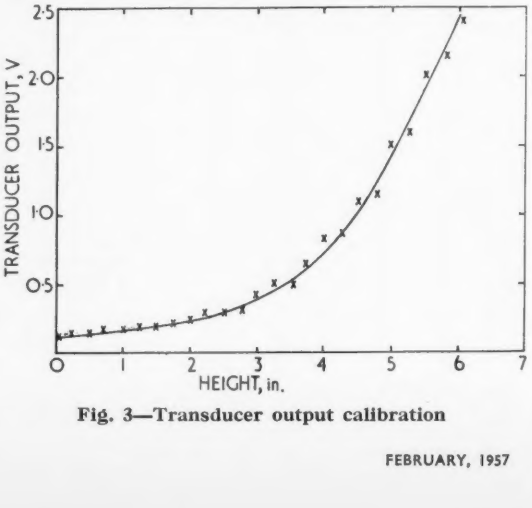

Fig. 3—Transducer output calibration

holes may be spaced along a channel formed in a single-turn or multi-turn spiral about the casting mould. With the mould dimensions shown, a three-turn spiral over a 6-in. vertical height has a length of approximately 15 in., which with similar hole spacing would permit about 50 steps in level indication over the 6-in. height.

This would have the effect of removing the difference existing between the points and the curve shown in Fig. 3 and smoothing out the steps by increasing their number. The vertical spacing of the holes being very much less, smaller changes in liquid level are required to alter the effective restriction and hence the pressure reading.

Fixed Restriction R_1

The fixed restriction R_1 consists of a plug $\frac{3}{8}$ in. long with a hole $\frac{1}{16}$ in. in diameter drilled through it. The choice of diameter and length must be made in conjunction with the number and arrangement of holes in the variable restriction R_2, and with the operating pressure, so that, with all the holes of R_2 uncovered, R_1 presents a high impedance relative to R_2.

Operating Pressure

The choice of operating pressure has certain limits. Higher pressures (of the order of several lb/in²) are desirable to minimize blockage of the holes, and to simplify the problems of regulation and pressure measurement. However, trouble is encountered at pressures above a few lb/in², owing to the air jet from the hole coincident with the liquid level impinging on the metal and forming a ' blow-hole,' giving rise to a defective cast ingot and, owing to incomplete closure of the hole, an incorrect pressure reading. This latter effect is unstable and gives, in fact, a small oscillation of the pressure reading. With the dimensions shown in Fig. 2, a suitable regulator setting is 1 lb/in² with a compressor generating about 15 lb/in².

Pressure Measurement

Any suitable method of pressure indication may be used but, to facilitate connection to an automatic control system, a pressure transducer has been used to give an electrical output. It is of the usual form, consisting of a member deforming under pressure. The flexible member is a Hydroflex bellows, linked to the potentiometer of a standard Type 548 Langham–Thompson transducer. Full electrical output corresponds to $1\frac{1}{4}$ lb/in².

The potentiometer is energized from a 6-V d.c supply, and the output pressure indication is a voltage between 0 and 3 V. The graph in Fig. 3 shows the variation of voltage from the transducer with change in level. To enable the level to be continuously recorded, an amplifier was designed to convert the signal from the transducer to operate a mA pen recorder. The characteristic of the amplifier was used to flatten the curve slightly and so reduce the non-linearity of the instrument.

TESTS OF THE INSTRUMENT

Static tests have been conducted in the laboratory using first lead, and later cast iron. By pouring the metal into the mould at a constant rate, the height of metal in the mould will increase at a constant speed. Hence, the indication of rate of change of level on the recorder could be assessed, and was found to conform with the curve shown in Fig. 3.

CONCLUSION

A pneumatic level indicator for the continuous casting process can indicate the liquid level over a height of 6 in. to an accuracy of $\frac{1}{2}$ in. A signal obtained from the indicator could be applied to control the casting process to maintain a constant level in the mould.

Acknowledgments

The authors gratefully acknowledge the original suggestion of Mr. J. Morton of Messrs. Campbell, Gifford and Morton, which led to the development of this instrument, and the advice and encouragement of Mr. J. Savage, Head of the Physics Department, during the course of this work.

Letters to the Editor

A New Experimental Technique for Studying the Blast-furnace Process

THROUGHOUT THE WORLD great increases in pig-iron production are planned. Some of the increase will have to come from higher productivity of existing plant, preferably without loss of fuel efficiency. Coupled with the changing raw-materials situation, this will set the ironmaking industry many problems in blast-furnace practice, the solution of which would be facilitated by the availability of satisfactory experimental techniques for: (1) detecting restrictions on productivity and fuel economy in the blast-furnace process; (2) evaluating the effects of changes in blast-furnace operation and design on productivity and fuel economy; (3) evaluating the quality of materials for the furnace. It is hoped that the technique briefly described here will fulfil these requirements. Although it has been tested only on a small scale (in collaboration with J. McKelvie, F. A. Wright, and P. Watson of B.I.S.R.A.) the results are considered sufficiently promising to justify, in view of its potential importance in the present situation, the publication of this brief account of its principles and operation. The technique is applicable to similar processes, such as the calcination of dolomite in shaft kilns.

Consider an ideal furnace, in which a perfectly distributed charge descends evenly, steadily, and without friction against the walls counter-current to perfectly distributed gas. The conditions (chemical composition, temperature, pressure, flow rate, etc.) will remain constant at any given level in such a furnace. Let us now take a set of equally-spaced levels A, B, C, D in Fig. 1*a* and consider what happens when a horizontal slice of the charge, initially between levels A and B, descends. Figure 1*b* shows that when it has descended through its own height, the conditions at its top (those of level B) have become what they were at its bottom when it started its descent. The next stage is shown in Fig. 1*c*, and it is evident that the same relation will hold for

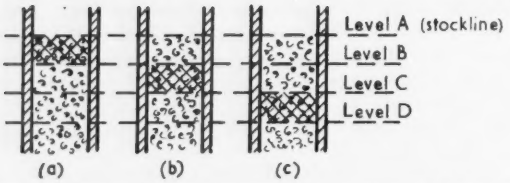

Fig. 1—Stages in the descent of a horizontal slice of charge down an ideal furnace stack. The slice is indicated by cross-hatching

any other pairs of levels, namely that the conditions at the top of the horizontal slice will lag behind those at its bottom by the time the slice takes to descend its own height.

The second basic principle of the method is that the difference between conditions at any two levels is due to the interaction of the gas and charge between those levels. This enables the difference in conditions between levels to be determined by experiments outside the furnace as follows. The container shown schematically in Fig. 2 is large enough to take a representative portion of the furnace charge and can be supplied with gas of any temperature, composition, and pressure at any flow rate, all these being measurable at the inlet (bottom) and outlet (top) of the container. The charge is fed into the container (through which gas is passing at the same rate, temperature, etc. as at the stockline) so that it builds up there at the same rate as it descends in the furnace. The gas entering the container is continuously adjusted at the inlet so that the conditions at the outlet remain, at this stage of the experiment, those of the furnace stockline. Then, because the actual furnace charge and conditions have been used, the inlet conditions when the charge height in the container is any given value must be those at the same distance below the stockline in the furnace. Referring to Fig. 1, when the height of the charge in the container is equal to the distance between levels *A* and *B*, the inlet conditions will be those of level *B*.

When a suitable charge height has been built up, no more is added and the inlet conditions are continuously adjusted in such a way that the outlet conditions are no longer constant, but lag behind them by the time the particular portion of the charge would take to descend through its own height in the furnace. In this way the portion of the charge taken is, in effect, followed down the furnace, time being substituted for motion.

Preliminary experiments, although on too small a scale (3-in. dia. container) to be applicable to the blast-furnace, have confirmed the principles and feasibility of the new technique and also showed (*see* (2) below) that it eliminates the arbitrary selection of experimental conditions, which is a defect of many existing experimental techniques (e.g. reducibility tests). It is intended to carry out future experiments initially with a container of about 20 in. dia. and with a probable charge height of about 2 ft, which should give useful results since wall effects will be minimized and sizes of charge components can be more realistic.

The main characteristics of the new technique are:

(1) Each experiment corresponds to a definite driving rate (represented by the inlet–outlet lag for a given height of charge and by the rate of gas flow) and a definite fuel efficiency (represented by initial conditions and coke/burden ratio).

(2) Incorrect choices of driving rate or fuel efficiency show up during experiments. This was demonstrated during the preliminary experiments when it was found that too high an initial CO_2 content led to this

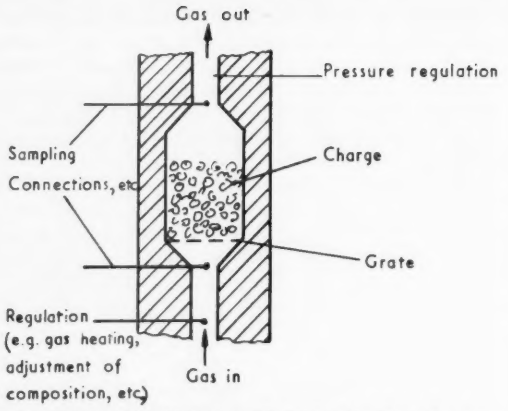

Fig. 2—Schematic diagram of apparatus for the new technique

gas being present at the inlet when there was no further possibility of the charge producing any; too low a content resulted in the charge still producing CO_2 after the CO_2 content in the inlet gas had been reduced to zero.

(3) By successive approximations, supplemented if necessary by heat and materials balances, possible driving rates and fuel efficiencies for various conditions of operation can be found.

(4) By experimenting with increasing driving rates and fuel efficiencies the corresponding restrictions can be found.

(5) (*a*) Detailed observations can be made of various processes involved in smelting, e.g. carbon deposition, carbonate decomposition; (*b*) temperatures at which various reactions occur can be found. Lumps can be withdrawn during experiments, repeat experiments can be stopped at different stages, radioactive isotopes can be used for studying the finer points of mass transfer, etc.

(6) The yield of information from an experiment can be increased by noting the effects on reaction rates, etc. of gas composition and other changes put into effect for such short durations as not to affect the general course of the experiment.

(7) By experimenting with different materials and conditions, ways of improving smelting can be tested. Possible examples are:

(*a*) the substitution of various types of self-fluxing sinter for raw carbonate,
(*b*) the use of high top-pressure,
(*c*) blast humidification.

(8) Experiments with charge materials of different qualities will indicate if any can be degraded without introducing difficulties; this information may enable the productivity of ancillary operations (e.g. sintering) to be increased.

(9) Since furnace-design factors can enter into the experiments, their influence can be studied. For example, stack batter is represented in the experiments by decreasing gas velocity and increasing lag time during the experiment.

(10) Though the technique is normally limited to temperatures below those of the fusion zone, detailed examination and testing of the charge during and at the end of the experiments will give indications of behaviour at higher temperatures.

(11) The accumulation of data on heat and mass transfer rates and other factors will enable an ever-increasing range of problems to be answered by

calculation. Combination of these data with those obtained when controlled departures are made from the normal technique, with data from model work, furnace exploration, and special tests should enable a useful picture of a real (i.e. non-ideal) furnace to be built up.

To sum up: the technique will enable various operating conditions to be reproduced outside the blast-furnace and studied far more effectively than is practicable on a working furnace, and far more cheaply.

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13th December, 1956

Protection of Arc-Furnace Bottoms

THE INSTALLATION of an electric stirrer beneath the bath of the 19-ft arc furnace at the works of Samuel Fox and Co., Ltd. greatly increased the possible damage associated with a break-through of steel. Such a break-through would not only result in the loss of valuable steel, together with loss of production due to damage to the furnace structure, but it might also result in the loss of the stirrer itself. Thus the cost of an elaborate warning system is warranted.

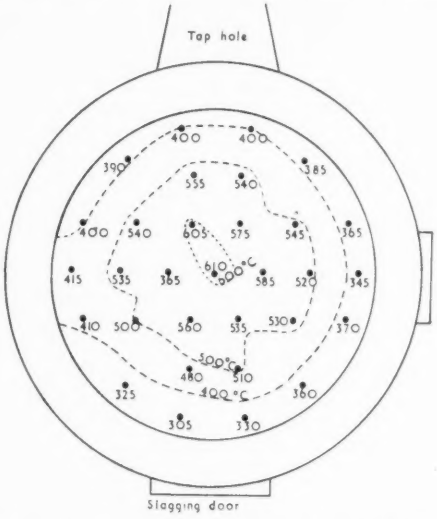

Fig. 1—Location of thermocouples and typical furnace-bottom temperature contours

The protective system installed consists of 31 thermocouples embedded in the brickwork of the furnace bottom so that they project through the 3-in. firebrick lining to the interface with the magnesite bricks. The advantage derived by inserting the thermocouples through the firebrick lining is a greatly reduced time-lag. The thermocouples are located evenly over the whole of the furnace bottom and are made from Pyrotenax wire. The section of this wire which is inserted into the brickwork has the outer sheath of heat-resisting steel and the cold end-seal of glass. The extension leads are in Pyrotenax but the outer sheath is of mild steel. This type of thermocouple was used because of its mechanical strength and its resistance to lead- and iron-oxide attack.

The output of each thermocouple is continuously recorded on potentiometric-type records. Alarm contacts operate should a pre-determined temperature level be exceeded.

This protective system has been in continuous use since August, 1955, and no trouble has been experienced with it. The thermocouples were replaced at the end of 1955 as a precautionary measure, but no signs of contamination were evident.

Experience has shown that the actual temperatures indicated by the thermocouples are not in themselves a warning of a possible weakness developing or of a possible breakthrough. Temperature levels appear to give a good guide as to bottom thickness, for low temperatures indicate that the bottom has been over-fettled, and high temperatures that it has been under-fettled. Thus the general temperature level provides the shop management and the melting personnel with a good guide as to the fettling condition.

Warning of the development of a bottom weakness is given by the system by a sharp rise in the temperature at one or more points. The rate of rise gives some idea of the seriousness of the defect which is developing. Neither a break-through nor a serious defect has yet occurred on the furnace bottom during the life of the bottom, which was replaced after 53 working weeks. However, as the occurrence of minor weaknesses has been indicated on the records, it seems reasonable to assume that the system is giving adequate protection of the bottom. Generally, a warning of at least one cast is given by the system of even a minor weakness.

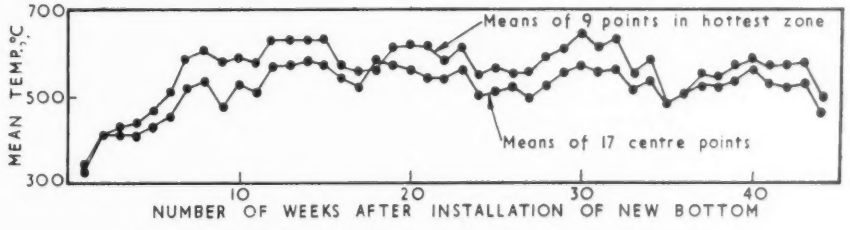

Fig. 2—Variation in mean bottom temperature with life

Figure 1 shows the location of the thermocouples in the furnace bottom, together with a typical temperature-contour chart which is plotted each morning for the information of the shop management. Figure 2 shows how the general temperature level of the bottom has varied, week by week, over the past 11 months.

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18th October, 1956

Effects of Microstructure on Electropolishing of Iron and Steel

THIS NOTE summarizes observations on the effects of microstructure on the current density required for satisfactory electrolytic polishing which were made during a series of microstructural investigations carried out in this laboratory on a diverse group of ferrous alloys. The compositions of the alloys studied are given in Table I.

Heat-treated specimens of these alloys were mounted in pairs in Bakelite. In most cases, a $\frac{1}{4}$ in. × $\frac{1}{16}$ in. surface of each specimen was exposed on the plane of polish. The mounts were ground and given a rough mechanical polish. Electrolytic polishing was performed on a Buehler-Waisman Electro-Polisher.* A hole was drilled into the back of each mount until contact was made with both specimens and filled with mercury in order to complete the electrical circuit. The electrolyte used contained 60 ml of perchloric acid, 110 ml of distilled water, and 590 ml of ethyl alcohol. Polishing times were held to 1–2 s to minimize rounding of the polished surfaces. The use of Bakelite mounts did not result in any dangerous reactions with the electrolyte during many hundreds of trials.

The current density required to obtain a good polish was found to be markedly dependent upon the microstructure. Although the current density varied during the short polishing times used, it was obvious that the optimum current density became larger as the mean free ferrite path† increased. Fully martensitic structures required the minimum current density, about 2 A/cm². Lower bainite and fine pearlite required slightly higher current densities; upper bainite and coarse pearlite necessitated the use of still higher densities, up to 3–4 A/cm² in the hypoeutectoid steels; in general, the current density increased slowly as the ratio of the percentage of isothermal transformation product to that of martensite increased. In specimens containing only proeutectoid ferrite and martensite, however, the current density needed rose rapidly when the ferrite crystals appeared in massive groupings, reaching about 4 A/cm² at 10% ferrite, about 7·5 A/cm² at 25% ferrite, and about 10 A/cm² at 100% ferrite.

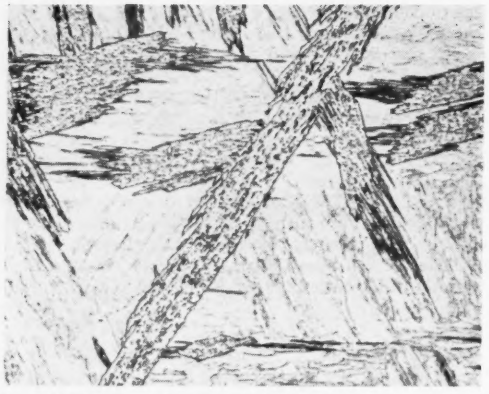

Fig. 1—Bainite and martensite in steel *A*. Austenitized 30 min at 1300° C, reacted 11 s at 475° C. Polished at 2·5 A/cm². Etched in 2% nital. ×1000

Figure 1 illustrates the quality of the polish obtained when the correct current density is employed.

Further evidence for the dependence of current density on mean free ferrite path was provided by the following observations:

(1) Some specimens of alloy *B* which had been reacted at 525–550° C contained more than 50% ferrite and very few carbide particles. The current densities required, however, were only 2·5–3 A/cm². Close examination of these structures showed that they were largely composed of thin plates of ferrite separated by martensite. The mean free ferrite path was accordingly relatively small. When this alloy was reacted at 750° C to approximately the same level of transformation, however, the ferrite appeared in massive form and a current density of about 8 A/cm² was necessary.

(2) Three specimens of alloy *J* had the following microstructures: (*a*) 10% cementite, balance martensite + retained austenite; (*b*) 50% fine pearlite, 1% cementite, balance martensite + retained austenite and (*c*) 100% martensite + retained austenite. A current density of 2 A/cm² polished all three specimens satisfactorily, as would be expected from the circumstance that the mean free ferrite path was very small in each case.

* Buehler Ltd., Chicago, Ill., U.S.A. Waisman[1] has published a description of the construction and operation of the original version of this apparatus. The commercial adaptation differs from the original primarily in the inclusion of a motor-driven pump and accessory internal compartmentation in the polishing cell in order to force up a carefully regulated stream of electrolyte against the surface of the specimen.

† As defined by Gensamer and co-workers,[2] this quantity is "the mean uninterrupted straight path through the ferrite."

Table I
COMPOSITION OF ALLOYS, %

Designation	C	Mn	Si	Cr	Mo	Ni	S	P
A	0·29	0·76	0·25	...	...	...	0·007	0·005
B	0·17	0·26	0·18	2·92	...	...	0·006	0·004
C	0·33	0·08	0·02	0·01	0·02	3·65	0·020	0·010
D	0·33	0·06	0·01	0·00	0·80	0·02	0·010	0·010
E	0·37	0·14	3·53	0·02	0·02	0·02	0·012	0·007
F	0·34	1·87	0·00	0·01	0·02	0·02	0·032	0·011
G	2·35	0·05	0·97	...	...	...	0·090	...
H	0·019	0·46	0·14	0·08	0·01	0·07	0·027	0·010
I	0·80	0·27	0·22	...	...	...	0·016	0·011
J	1·51	0·90	0·24	...	...	...	0·004	0·002

(3) Attempts to polish pairs of specimens which differed markedly in mean free ferrite path normally resulted in a satisfactory polish being obtained on only one specimen.

In agreement with Merchant,[3] the cell voltage was not a critical factor in the polishing process. Voltages ranging from 35 to 90 V were used in the present studies to obtain the desired current densities.

No effect upon current density was found which could be directly attributed to either the carbon or the alloy contents of the materials investigated.

The appreciable effects of microstructure upon current density reported here were not found by either Merchant[3] or De Sy and Haemers.[4] Differences in electrolyte composition may be partially responsible for this divergence.

The authors express their appreciation to the Aeronautical Research Laboratory, U.S.A.F., and to the Office of Naval Research, U.S.N., for sponsoring the investigations on which this note is based and to Dr. R. F. Mehl and Mr. P. E. Busby for valuable discussions. Reproduction in whole or in part is permitted for the purposes of the U.S. Government.

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29th June, 1956

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2. M. GENSAMER, E. B. PEARSALL, W. S. PELLINI, and J. R. LOW, jun.; *Trans. Amer. Soc. Metals*, 1942, vol. 30, pp. 983–1019.
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4. A. L. DE SY and H. HAEMERS: *Stahl u. Eisen*, 1941, vol. 61, pp. 185–187.

Correspondence on the Paper—

A Study of the Impact Properties of Boron-Treated Steel*

By S. J. ROSENBERG and J. D. GRIMSLEY

(The main part of the discussion was published in the December, 1956, issue of the Journal, pp. 456–461).

Mr. **Rosenburg** wrote in reply to the discussion: Both Dr. Woodfine and Mr. Jackson express doubt as to whether the authors' conclusion is correct that titanium in the addition agents is conducive to increased susceptibility to temper embrittlement. In support of this doubt, they point to Fig. 20 of the paper. The authors have re-examined this figure by comparing the maximum shift in transition temperature, determined by each of the various criteria, caused by addition agents both with and without titanium but without regard to the type of agent or amount of boron. The following figures are of interest:

	Maximum Shift in Transition Temperature, °F	
Transition Criterion	*Agents containing* Ti	*Agents without* Ti
$\frac{1}{2}(E_{100\%B} + E_{0\%B})$	17	12
A.T.S. (area measurements)	24	14
20 ft-lb	39	31
40 ft-lb	31	19
100 % brittle fracture	14	− 20
50 % brittle fracture	41	19
0 % brittle fracture	50	20

It is significant that in each instance the maximum shift was greater with the agents containing titanium than with those that did not. If these various figures are averaged, it will be seen that the maximum shift in transition temperature caused by the titanium-bearing addition agents was 31° F, while that caused by the titanium-free addition agents was only 14° F. Each of the graphs in Fig. 20 contains 15 points representing titanium-bearing agents, and 5 representing titanium-free agents. Calculation of the average shift caused by each of the two groups gives the following tabulation:

	Average shift in Transition Temperature, °F	
Transition Criterion	*Agents containing* Ti	*Agents without* Ti
$\frac{1}{2}(E_{100\%B} + E_{0\%B})$	4	− 6
A.T.S. (area measurements)	12	4
20 ft-lb	19	15
40 ft-lb	18	5
100 % brittle fracture	− 8	− 23
50 % brittle fracture	25	12
0 % brittle fracture	18	11

Again, it is significant that in each instance the average shift was greater with the agents containing titanium than with those that did not. Averaging these figures indicates the transition temperature was shifted 13° F by the titanium-bearing addition agents as compared with a shift of only 3° F caused by the titanium-free addition agents. Although, as noted in the paper, the authors are not entirely satisfied in using the shift in transition temperature as a measure of temper embrittlement, Dr. Woodfine notes that there seems to be no alternative. In view of this, the figures given above assume added significance and give further support to the authors' conclusions.

In connection with this phase of the discussion, and particularly in reply to Mr. Jackson, it is pertinent to note that additional data, to be published very shortly, show quite definitely that titanium tends to increase the susceptibility of steels to temper embrittlement.

Dr. Woodfine notes that the A.C. specimens may show some temper brittleness themselves. Theoretically this is possible, but practically, the rate of air cooling of such small sections as impact specimens is sufficiently rapid so that usually there is no significant difference between the impact energy/test temperature curves of W.Q. and A.C. specimens. The authors have considerable data that point up this fact and these data will be published shortly.

The authors believe that their Figs. 8 and 12, summarizing the curves of the steels treated with the simple intensifiers, are significantly different from the other figures summarizing the curves of the steels treated with the complex intensifiers. This is particularly true for the curves representing the furnace-cooled steels. Dr. Woodfine's reference to the curves of Fig. 12 showing the steels tempered at 800°, 900°, 1000°, and 1100° F indicates that his criticism is well founded; perhaps the authors should have used the figure of 0·0020% B instead of 0·0025% in their conclusions. It is quite definite from Fig. 12 that 0·0016% B is without any significant effect and Fig. 8 shows that even greater amounts are not entirely significant. Perhaps, as Dr. Woodfine says, the simple intensifiers are not so simple after all.

The authors wish they could say that the compositions of Table I, showing apparently more than 100% recovery of boron for steels C8 and C9, were typographical errors, as Dr. Woodfine so charitably suggests. However, the analytical figures are correct, but the authors have no way of knowing whether the figures for the amount of boron added are correct as these were furnished by the manufacturer of the steel.

* *J. Iron Steel Inst.*, 1956, vol. 182, March, pp. 278–292.

IRON AND STEELWORKS ENGINEERING

The Iron and Steel Engineers Group

IRON AND STEEL ENGINEERS GROUP

REPORT OF THE THIRTY-FIRST MEETING

THE THIRTY-FIRST MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held in South Wales on Thursday and Friday, 4th and 5th October, 1956. The technical sessions were held in the Grand Pavilion, Porthcawl, with Mr. W. M. LARKE, Chairman of the Group, in the Chair.

The following paper on " The Engineering Aspects of a Modern Basic Bessemer Plant " was presented at the first technical session, on Thursday, by Dr. C. Herrmann, Demag AG, Duisburg, Germany, and discussed; a report of the discussion is given on pp. 261–263.

Engineering Aspects of Modern Basic Bessemer Plants

By Dr.-Ing. C. Herrmann

SYNOPSIS

A distinction can be made between four stages of development in the layout of basic Bessemer steelworks. The fourth and last stage of development has been initiated only in the past decade and is characterized by a significant increase in converter sizes and far-reaching rationalization of the operating process. Blowing with oxygen mixtures or pure oxygen necessitates special constructional measures, such as the fully mechanized charging of admixtures and cooling agents.

The shape of converters, the hydraulic tilting mechanism, and pressure-water plant involved, together with regulation problems arising when oxygen mixtures are used for the blow, are dealt with in detail.

Examples given of a modern dolomite and slag treatment plant show that fullest consideration is now given to hitherto neglected auxiliary plants. The development work so far carried out on waste gas cleaning systems has made it evident that plant suitable for practical operation can be set up within the foreseeable future.

1372

A HUNDRED YEARS AGO Henry Bessemer created the basis for the pneumatic conversion process. His fellow countryman, Sidney Gilchrist Thomas, paved the way two decades later for the utilization of phosphorus-bearing ore deposits for producing steel on a large scale—a development of decisive importance for the European continent. In the short course of 11 years, from 1879 until 1890, European annual production of basic Bessemer steel rose to 2·5 million tons, had tripled itself by 1903 to 7·8 million tons, and by 1955 had reached a total of 26·5 million tons produced by the basic Bessemer process.

To obtain some idea of the difficulties which had to be overcome in developing the basic Bessemer process to a large-scale technical process it must be remembered that in the first years of the process's history neither mechanical engineering, developed to such a high pitch as it is today, nor electrical engineering,

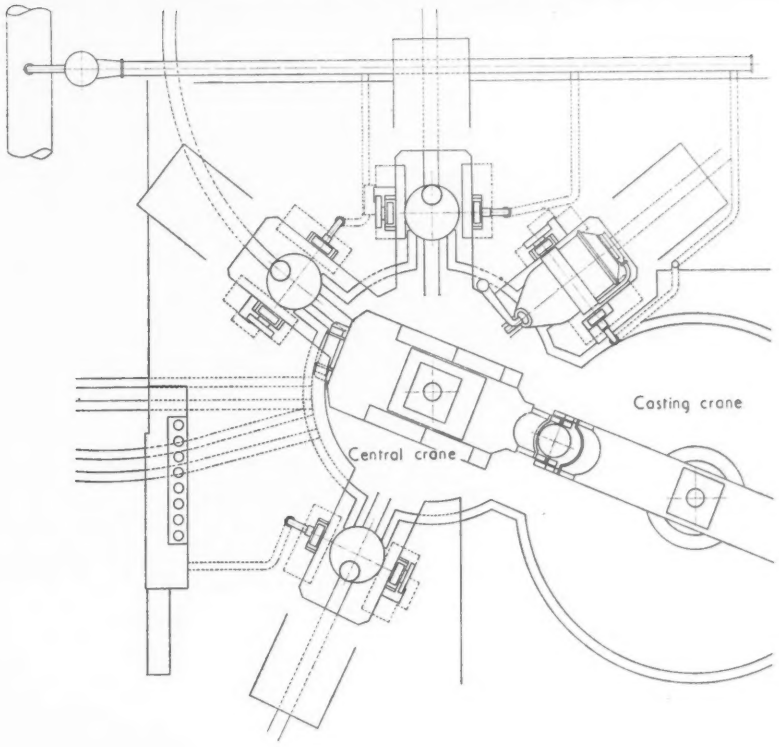


Fig. 1—Circular arrangement of the converters at the Phoenix metallurgical works in Ruhrort

which is nowadays employed so extensively in metallurgical plants, were in existence.

THE HISTORY OF THE LAYOUT OF BASIC BESSEMER STEELWORKS

First Stage of Development

According to Brandi,* four stages of development can be distinguished in the layout of basic Bessemer steelworks. In these stages the progress of metallurgical research, mechanical design, and rationalization, becomes evident. The first stage of development, corresponding to Bessemer's own sketches, has the converters arranged in a circle around a central hydraulic slewing crane. This arrangement persisted for a long time and was utilized again and again for every steelworks, wherever, and by whomsoever, it was built. The oldest plant of this type still working on the continent, at the Phoenix metallurgical works in Ruhrort, is shown in Fig. 1. Four basic Bessemer converters, each of 15 tons capacity, which still produce 30,000 tons of steel a month, are arranged in a circle around the central crane. The molten iron is brought up by rail in cars. The central crane grabs the hot-metal ladle and raises it hydraulically for emptying at the level of the converter mouths.

The upper platform of the central crane serves as a working platform and can be brought into position in front of each converter by slewing and raising the crane.

Auxiliary operations (such as transporting the ingots, ingot moulds, and ladles) used to be carried out by several stationary slewing cranes with an operating range overlapping the slewing range of the casting crane. These auxiliary operations are now performed by an ingot handling and stripping crane.

The characteristic features of this first stage of development are therefore:

the circular arrangement of the converters,
the exclusive use of stationary slewing cranes, and
the casting into circular pits.

These features set natural limitations on the number and size of the converters. It is impossible to arrange more than four converters in a circle. Moreover, one central crane cannot serve more than two converters working simultaneously—which is the case where there are four converters. The size of the converters is limited by the capacity of the casting pit, the length of which is determined by the slewing radius of the stationary slewing crane. Space is not available to install a second casting crane, and setting up circular systems beside each other is both irrational and expensive.

Second Stage of Development

Before the end of the last century new ways were sought and found to avoid these natural limitations.

* *Stahl u. Eisen*, 1954, vol. (74)S, pp. 1262–1267.

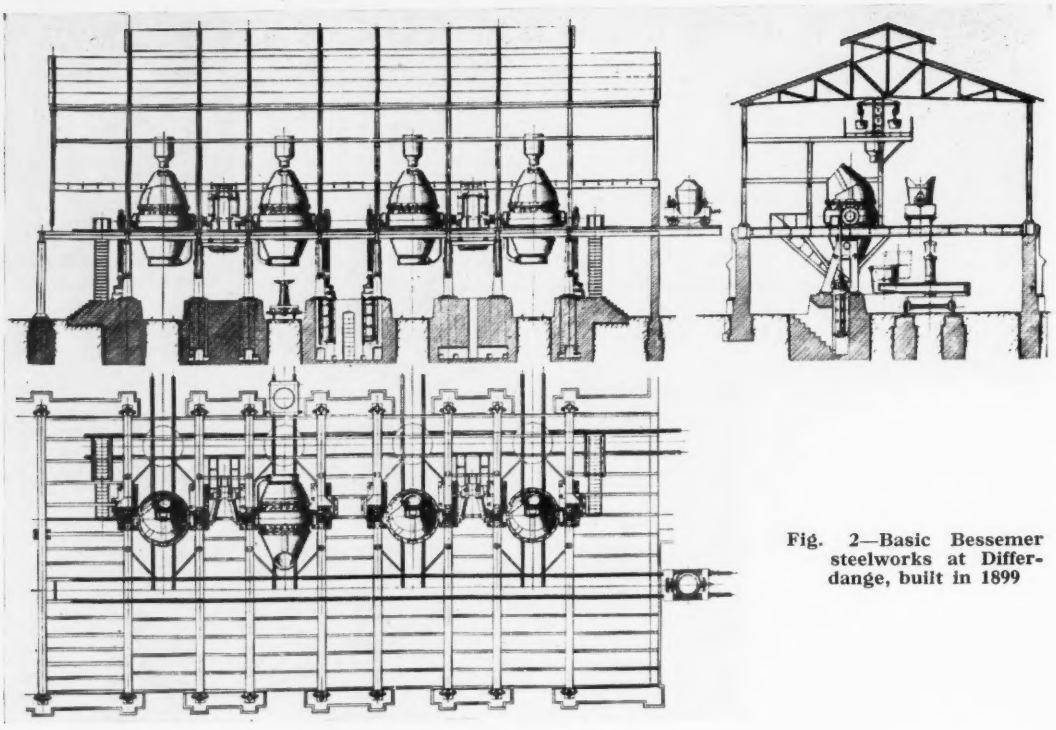


Fig. 2—Basic Bessemer steelworks at Differdange, built in 1899

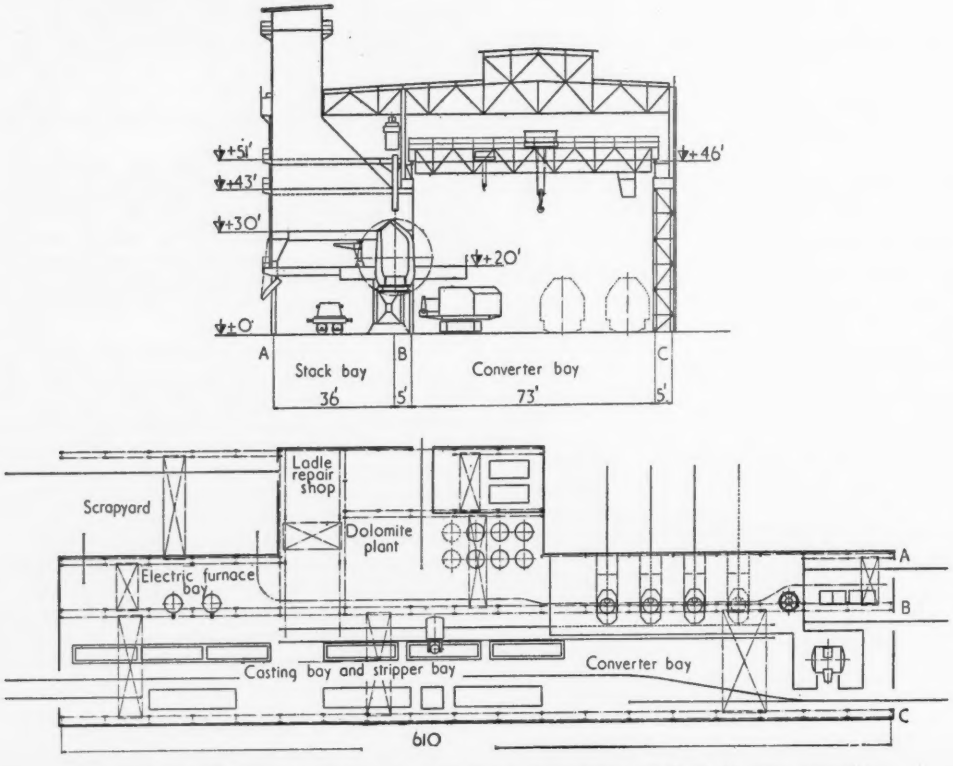


Fig. 3—Basic Bessemer steelworks with three converters, each of 17-tons capacity

The converters were arranged in a row and the hot metal was brought up over a ramp on to the converter platform, which serves as a working platform. The finished steel is taken over by a steam-driven casting car and travels along the row of converters to the casting pits, arranged parallel to the rails, where it is poured out.

Figure 2 shows such a plant installed for Hadir in Differdange (Luxembourg) in 1899 and still working today. The hot-metal car with the tiltable ladle, which enables the hot metal to be poured into the converter without the help of a crane, can be seen on the converter platform. The apparatus for charging lime and other admixtures, which can be regarded as a precursor of present-day automatic equipment, is above the converter. The casting car travels along the row of converters to the casting pits. The fact that this car travels lengthwise through the bay enables the length of the casting pit to be increased and group teeming to be carried out as necessary.

The characteristics of the second stage of development are therefore:

the arrangement of the converters in a row,
the steam-driven casting car,
casting into pits arranged parallel to the casting car track, and
bringing up the hot metal over ramps.

Heavy cranes for charging the hot metal and pouring the steel were not used in this second stage of development. Steam-driven ladle cranes were, indeed, being built at that time but they were unwieldy and particularly liable to breakdown.

Third Stage of Development

The development of reliable, powerful electric cranes marks the third stage of development. The converters are still arranged in a row and the casting cars travel lengthwise through the bay with casting pits on both sides of the casting cars' tracks.

The hot-metal mixer, which has meanwhile been acknowledged as necessary, is served by a ladle crane, and the tapped hot metal is also brought to the converters by this crane. The approach ramps, regarded as obstacles cutting across the working area during the second stage of development, are thus dispensed with.

At the same time, the steam-driven casting car has been replaced by the electro-hydraulic or all-electric car. As in the second stage of development, an arrangement using more than four converters necessitates two casting cars, which necessitates adherence to a fixed blowing programme if the full capacity of the steelworks is to be achieved.

Whereas the converter capacity in the first two stages of development was generally around 15 tons, converters for the third stage hold between 30 and 40 tons.

This arrangement is in accordance with contemporary views on the layout of small-capacity, basic Bessemer steelworks and Fig. 3 shows a plant of this type which is being built at present, with three converters of 17-tons capacity each. It is possible to add a fourth converter. The three converters are arranged along the line of stanchions *B*. The mixer (with a capacity of 500 tons) and the casting equipment are set up in the continuous bay *B–C*. Two 12-ton electric-arc furnaces are provided to process all the home scrap of the works and to cover the requirement of high-quality steels. The auxiliary equipment of the steelworks is located in the same building and arranged as rationally as possible. For example, the ladle repair shop is outside the casting shop but connected with the casting-car track by a crosswise travelling crane. The dolomite plant is set up in such a way that the bottoms can be brought up underneath the converters by their trolley without being transported out in the open. The lime bins are located beyond the row of converters in line with them.

A ladle crane is used for the mixing operations, and this transfers the hot metal from the mixer to the converters as well. After blowing, the steel is brought by the casting car to the three casting pits and bottom-poured to ingots weighing 1·5 tons. After the pouring operation the casting car returns the empty ladle to the ladle crane. The casting car then takes over the new ladle which has been brought up and can thus travel back to the converters without any great loss of time. This arrangement has been used successfully for more than 20 years in the Japanese basic Bessemer steelworks of Nippon Kokan Kaisha Ltd. in Kawasaki.

The lime for the converters is taken from elevated bins in the lime bay which are charged with the help of a travelling crane. The lime is conveyed to the bins above the converters by one of the two hoist-equipped monorail trolleys.

To sum up, the features of progress made in the third stage of development are:

the introduction of heavy casting cranes for transporting the ladles,
the electrification of crane drives and the casting car,
augmentation of the capacity of the converters.

Fourth Stage of Development

The fourth and latest stage of development has been initiated only in the past decade. Improvements in output and quality, as well as extensive rationalization of working operations, were the determining factors of the new lines of development. Prime cost and metallurgical considerations, above all, have led to a leap in the size of converters, and nowadays large-capacity converters containing 50 tons and more are commonplace. The previous dual function of the casting car—to transport steel and to pour—does not apply in these large plants, since transport and pouring times exceed the heat sequence. Steel transfer cars travelling crosswise separately bring the steel casting ladles into the casting bay, where they are taken over by casting cranes. Pouring follows into moulds standing on mould cars, which are dispatched lengthwise along the bay into the casting shop or across the bay to take the steel (after it has been cast) into the adjacent stripping bay. These two systems necessitate a different layout for the stripping and soaking-pit bays.

Bessemer recognized the decisive importance of oxygen more than a hundred years ago. However, decades were to pass before the technical prerequisites for the manufacture of oxygen on an economic basis were realized. It is only in recent years that any gas

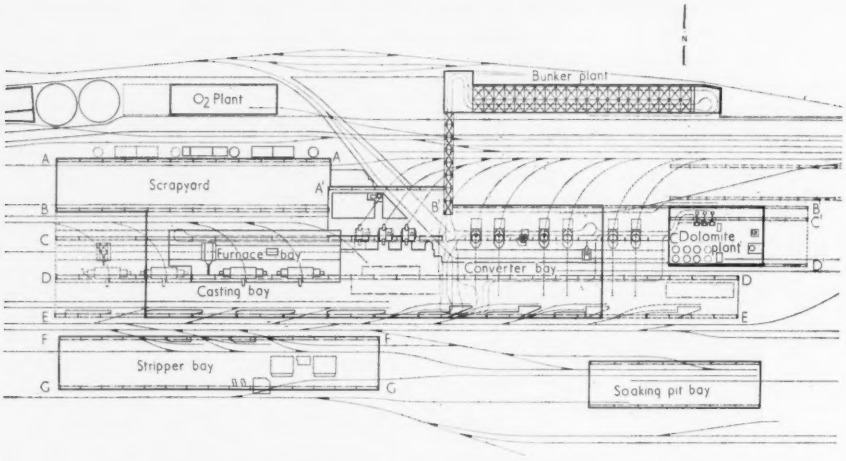


Fig. 4—Ground plan of Sollac's basic Bessemer steelworks in France

other than air has been used for blowing. An air–oxygen mixture, or a combination of steam and oxygen is preferred, where the highest demands on quality are involved. The additional use of oxygen, whether in an air–oxygen or steam–oxygen mixture, makes it possible to reduce considerably the nitrogen content of steel and thus to open up new fields of application for basic Bessemer steel process.

These processes involve special building measures so that necessary admixtures and cooling agents such as lime, limestone chippings, scrap, ore, etc., can be conveyed into the converter by fully mechanized installations and the charges weighed. Moreover, blowing with oxygen mixtures presents new problems which have only been solved recently.

A steelworks incorporating in its layout the characteristic features of this latest stage of development has been built for Sollac in France. The plan is illustrated in Fig. 4. The combined basic Bessemer and O.H. steelworks has a central mixing plant, with the O.H. steelworks on its western side and the basic Bessemer steelworks adjacent to the east. The mixing plant consists of two circular mixers each of 1150-tons capacity. In the final construction there will be three mixers, each compact, short in length and having electric tilting mechanisms. The central location of the mixers has the advantage that hot metal does not have to be transported far, either to the converters or to the O.H. furnaces. The arrangement also allows unrestricted extension of the basic Bessemer and O.H. steelworks. The mixers and converters are arranged along the row of stanchions *C*, while the O.H. furnaces were relocated along the row of stanchions *D*. The arrangement of the converters and furnaces all in one bay *C–D* facilitates the application of the duplexing method. The tracks leading to the mixing plant could be laid down along old slag heaps on the same level as the mixer platform. The hot-metal cars are sent directly on to the mixer platform via a twin-track bridge, and thus awkward track junctions are avoided.

At present four large-capacity converters, containing between 50 and 55 tons each, are employed in the basic Bessemer steelworks. These will be supplemented by two further converters of the same size in the final stage of construction. The arrangement of the converters in three groups of two converters each, with clear intermediate spaces, has proved very successful, as only in this way can a detrimental piling up of operations in the casting bay be avoided.

Between the mixing plant and the converters enough space has been provided for a desulphurizing plant to be set up at a later stage.

The arrangement chosen for the converters and O.H. furnaces makes it possible to cast steel from both of them in a common casting bay. The basic Bessemer steel is brought into the casting bay by steel transfer cars travelling crosswise. Casting takes place exclusively into moulds on cars in view of the high capacity of the steelworks. Three casting stands are set up along the bay for casting the O.H. steel, and six stands are available for casting the basic Bessemer steel. After the steel has been cast and has stood, the slabbing ingot moulds on the mould cars are hauled out of the bay by diesel locomotives and taken into the adjacent stripping bay. The moulds are lifted off the ingots by stripping cranes and deposited on cooling grids. The slabbing ingots remaining on the cars are then dispatched into the soaking-pit bay and charged into the soaking pits. When the empty mould cars have been returned to the stripping bay, new moulds are placed on them, and the assembled trains are shunted into the casting bay. Ladling operations are carried out in the centre section of the casting bay, between the O.H. plant and the converters. In addition to the casting crane, a semi-gantry slewing jib crane is employed in this bay for auxiliary work.

The bins are located to the north of the basic Bessemer steelworks. All materials needed in the whole steelworks, such as ore, lime, dolomite, limestone chippings, coke, anthracite, sand, soda, etc., are conveyed by car over the ground storage bins, into which they are emptied. A telpher line connects the bins with the steelworks. This line leads up an

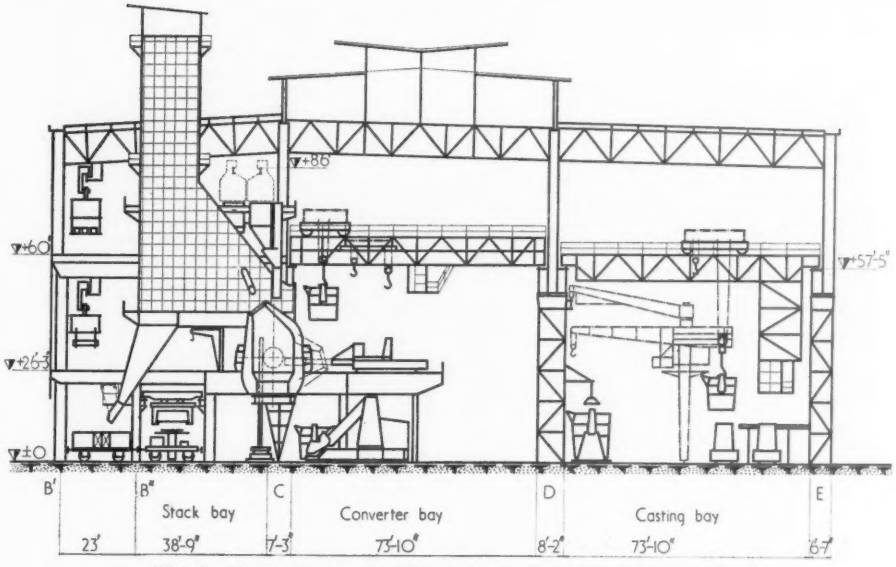


Fig. 5—Cross-section of Sollac's basic Bessemer steelworks

incline into the steelworks and then divides up into several circuits; one of these leads to the basic Bessemer steelworks and the dolomite plant, a second to the O.H. steelworks, and a third to the parking station over the casting bay.

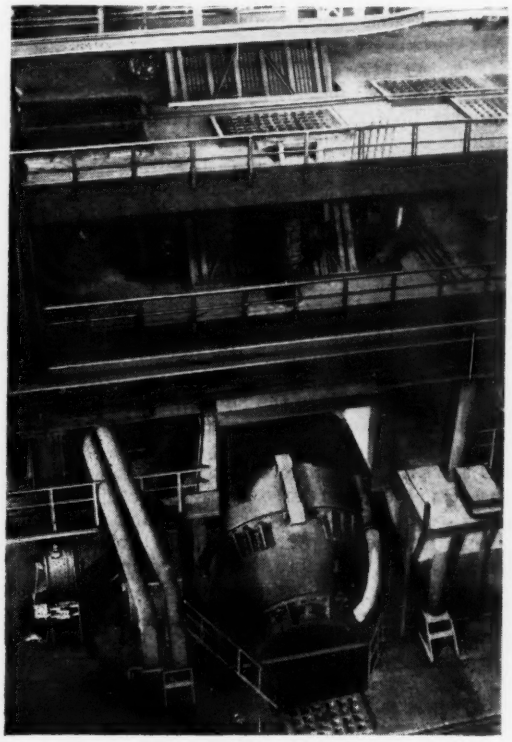


Fig. 6—View of the platforms along the row of Sollac's converters

The dolomite plant is set up to the east of the converter bay in the same line. From here the burned converter bottoms are conveyed by their special trolley (*see* Fig. 5) beneath the converter tracks, where they are taken over by the converter bottom jack cars and installed in the converters.

Sollac's converter stacks are provided with cast plates, which have proved suitable for the air-blowing process. If oxygen mixtures are used, a minimum requirement is to furnish the exposed places of the stack with ceramic plates containing a graphite additive. The stacks of new plants are usually completely furnished with these firebrick graphite plates. In this way the stacks can stand up to the highest temperatures and deposits of stack skull are obviated.

The scrap platform is located above the converter and stack platform at a height of about 60 ft. Scrap is brought up by means of a monorail trolley with driver's cab combined. Scrap charging cars with tippable boxes then take it over and travel across the bay before transferring the scrap to the converter chutes. The bins for the admixtures such as lime, ore, and limestone chippings are located on the lime platform above the scrap platform. In addition, there is a bin for stiffening lime beside each converter. The lime bins have gates which are remote-controlled from the converter control stand. Stiffening lime can be charged into the converter by hand, as well as by the charging machine travelling along the row of converters. A plate-conveyor belt, installed under the ore and limestone-chipping bins, caters for the correct admixture of the cooling agents charged. The belt is push-button operated from the converter control stand, which has an indicator to show what quantities are admitted into the converter. The slope of the feed tubes is so selected as to minimize the risk of the cooling agents being swept along by the force of the blast.

Fig. 7—Sollac's converter bay in the course of erection

As mentioned previously, the steel is brought into the casting bay by means of steel transfer cars travelling across the bay. As, in this particular case, the introduction of the Perrin process is envisaged, the steel casting ladle under the converter must be lowered to floor level to obtain a thorough mixing of the reaction slag in the ladle as a result of the large drop. The ladle is raised and lowered on two inclined tracks, the slope of which is chosen so that the car does not have to be moved when the converter is emptied normally.

Figure 6 shows the individual platforms of the basic Bessemer steelworks. Above the converter platform, where the feed tubes for the stiffening lime end, the stack platform is visible. Further up there is the scrap and lime platform where the openings can be seen, into which the contents of the flux bins described above are emptied. One of the rails of the telpher system is visible at the top of the figure. Figure 7 shows the converter bay during erection. Two converters having already been installed, the next converter vessel is being manoeuvred into position for the fitting of the trunnion ring. Lime bins are arranged above the mixers so that the mixer slag can be stiffened.

Good ventilation of the steelworks is achieved by means of a double ridge turret on the roof (*see* Fig. 5).

The principles adopted by Sollac have been developed further in the planning of the basic Bessemer steelworks for the Abbey Works of The Steel Company of Wales Ltd. Figure 8 shows the ground plan of the projected steelworks. Beside the mixer plant, which is to have two mixers with a capacity of 1200 tons each, there is the group of four 50-ton converters. In this case, too, the steel ladle is brought into the casting bay by steel transfer cars travelling crosswise. The bay has casting stands set up along it, each of which is capable of receiving one charge. The dolomite bay is located beyond the row of converters in the same line, so that, here also, transport takes place over short distances. The admixtures are brought over the lime platform from the main bins, which are charged by a conveyor system, via a telpher line. This works will produce only those qualities of steel which require a steam–oxygen mixture for blowing. The special requirements for this type of process, such as the particular shape of converter, the regulating system, and the dolomite plant needed, will be referred to later.

Before dealing with the converter bins (*see* Fig. 9) reference must be made to the supply of the converters with scrap. At the Sollac plant the scrap, which was charged from the scrap platform, had naturally to be sorted. When blowing with oxygen-enriched air, quantities of scrap up to 15% and more can be charged—according to the analysis of the hot metal. Considerable expense is involved in the preparation of such large quantities. Also, crops are often used and these must be charged at the beginning of a blow on account of their large size and the long melting period required. For this reason, Sollac have recently charged all the scrap into the tilted converter, via a steel-plate chute, before the blow commences.

This course has been adopted also by The Steel Company of Wales Ltd., although the quantities of scrap charged in the steam–oxygen blowing process are considerably smaller. The scrap is dispatched through chutes from the scrap yard into the converter bay, where it is weighed and quantities are adjusted. A light overhead travelling crane is used for charging scrap into the converter. Co-ordination of overhead travelling cranes for hot metal and scrap is

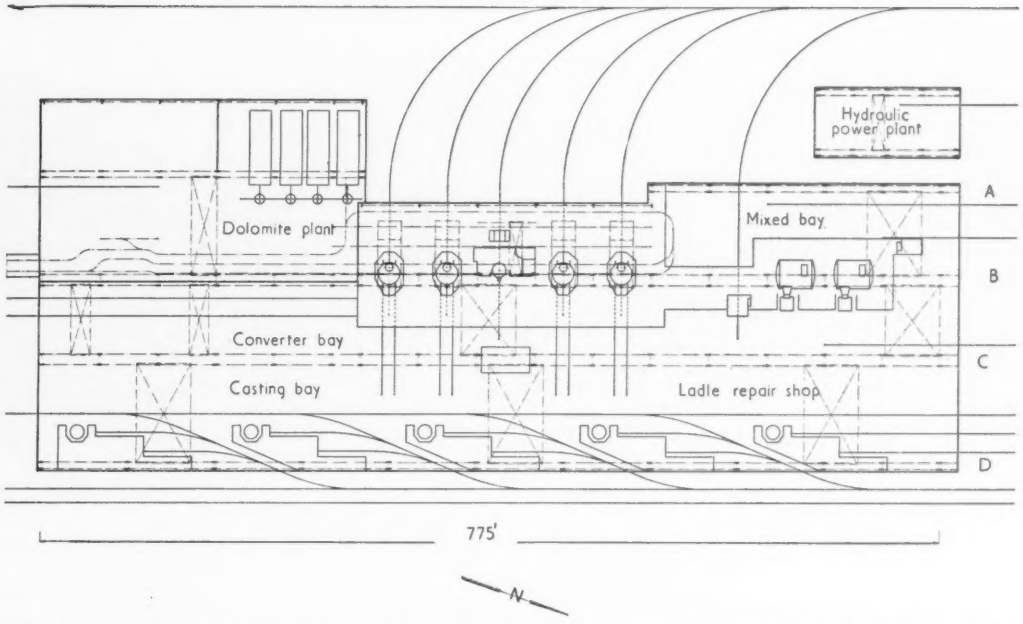


Fig. 8—Ground plan of the projected basic Bessemer steelworks of The Steel Company of Wales, Ltd.

unimpeded in this case, as hot metal is brought up on only one side of the row of converters, while scrap is brought up on the other.

A cross-section view of this steelworks (*see* Fig. 9) illustrates, from left to right, the casting bay, the converter bay, and the stacks. Here, also, particular importance has been attached to the ventilation of the converter bay. As opposed to the arrangement at Sollac, the converter stack is now completely lined with firebrick graphite plates. Also, whereas at Sollac the cooling agents, ore, and limestone chippings are brought up on a plate conveyor from the bins on the lime platform for the quantities to be weighed, the bins here are designed as weigh bins and include a number of intermediate bins as receptacles for the quantities necessary for a charge in each case. The

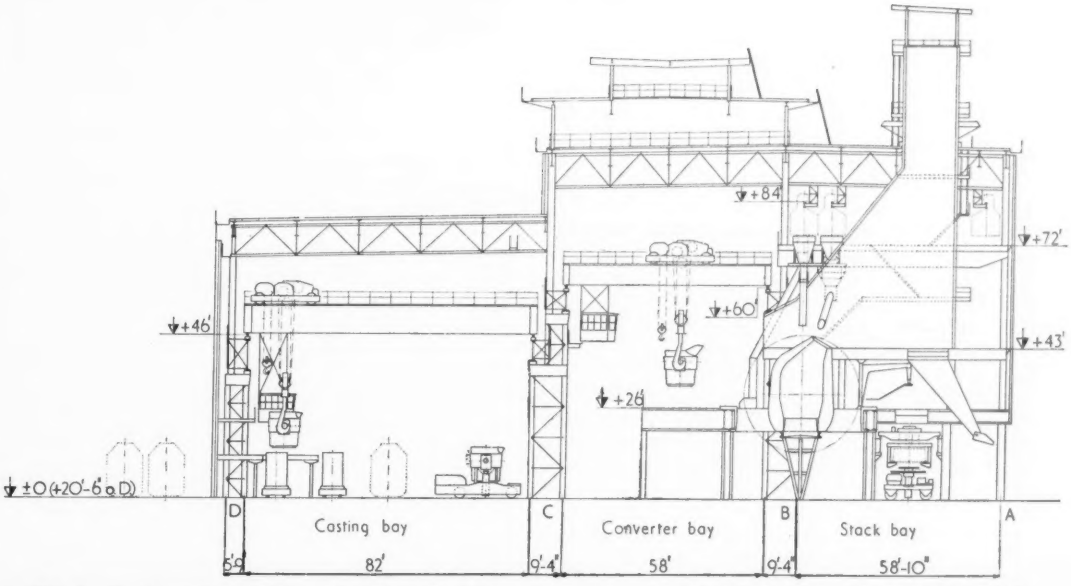


Fig. 9—Cross-section of the projected basic Bessemer steelworks of The Steel Company of Wales, Ltd.

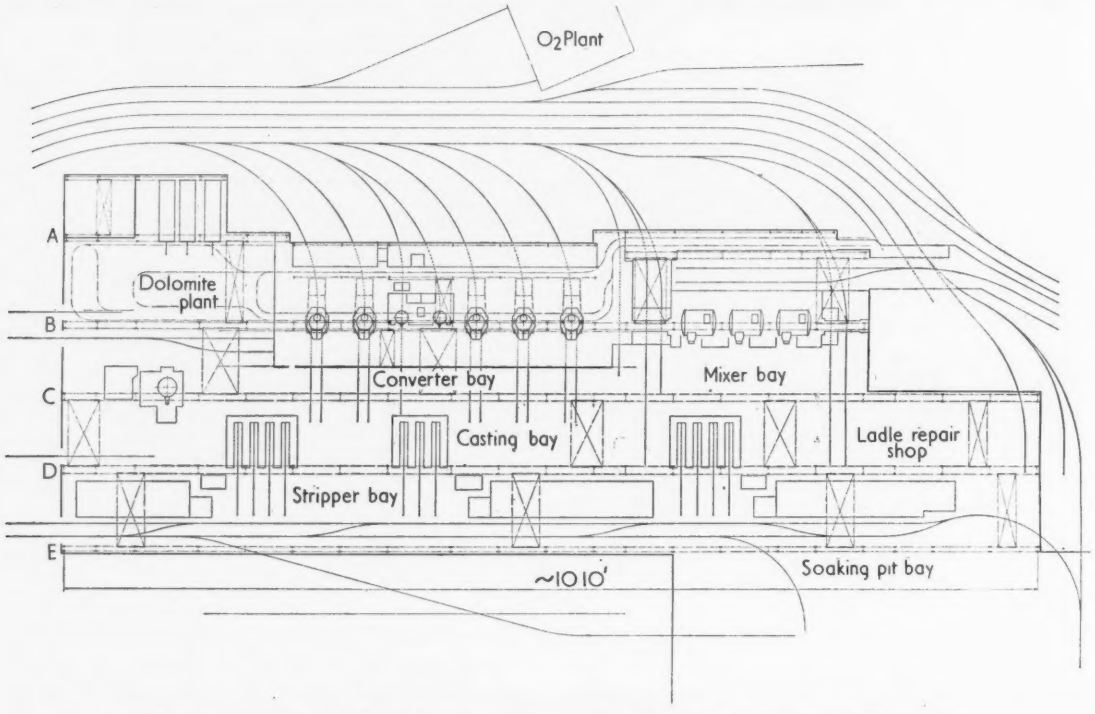


Fig. 10—Ground plan of the new basic Bessemer steelworks of Hadir at Differdange

weight is recorded at the converter control stand, so that the operator can adjust the exact weight before the cooling agent is charged. This is done by opening the pneumatically operated gate. All the material is precipitated as a compact mass into the converter, so that the danger of its blowing out is almost completely eliminated. The bins for the converter lime are also designed as weigh bins. However, in this case, an intermediate bin is not necessary as, in practice, the whole of the bin contents are used for one charge, and adjustments can be made by closing the gate early when required. Here, too, the converter operator can read the quantity charged from an indicator.

Both steelworks employ a system whereby the steel is cast at stands set up along the bay and is then shunted by locomotives into the separate stripping and soaking-pit bays. This casting system is employed in the U.S.A. to the virtual exclusion of every other. Its advantages include the physical separation of the casting, stripping, and soaking-pit bays. Disadvantages are incurred in the high cost of transportation, as both ingots and moulds have to be dispatched to the stripping bay. Furthermore, difficulties arise in the use of group teeming. If groups and pouring gates, which have been prepared in the stripping bay, have to be shunted over several points, there is always the danger that they will be displaced and that break-outs will occur in casting.

As group teeming is still used predominantly in Europe at present, a method of working has been developed in which the ingot mould cars are shunted smoothly over only a short distance. As an example of this, Fig. 10 shows the ground plan of the basic Bessemer steelworks for Hadir in Differdange (Luxembourg), which is now being erected. Next to the mixer plant, which consists of three 1300-ton mixers, there is the converter plant consisting of five 50-ton converters set up in two groups. The dolomite plant is arranged beyond the row of converters in the same line. The steel blown in the converter is transported into the casting bay by steel transfer cars travelling across the bay in this case too. The stripping bay is next to the casting bay.

The steel is cast from eleven casting stands, divided into three groups which are set up across the bay. Each casting stand is designed to cater for one heat. After casting and the usual cooling-off period, the ingot mould cars from the casting stand are hauled off to the adjacent stripping bay, where the moulds are stripped and the ingots placed on ingot cars. These are then shunted by the locomotive into the old soaking-pit bay. The ingot mould cars can be moved on the casting stands either by electrically driven winches or they can be self-propelled. Both these systems have worked satisfactorily for some years at the basic Bessemer steelworks of the Salzgitter, Mannesmann, and Phoenix metallurgical works.

In new steelworks the soaking-pit bay can be built on to the stripping bay and the crosswise tracks for the ingot mould cars can be extended into the soaking-pit bay. It is then possible to shunt the ingot mould car train into the stripping bay after casting, strip the moulds, and subsequently move the train on into the soaking-pit bay, where the ingots can be charged

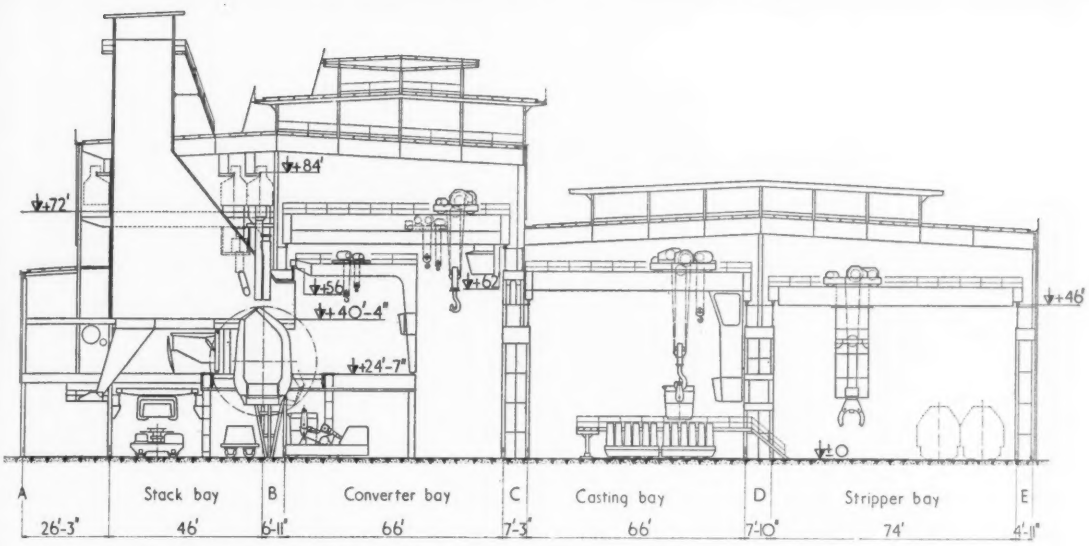


Fig. 11—Cross-section view of the new basic Bessemer steelworks of Hadir at Differdange

by crane into the soaking pits. This arrangement keeps heat losses and transportation costs to a minimum. The scrap is removed from the casting, stripping, and soaking-pit bays on the crosswise tracks in this case, too, and taken through the row of converters.

The semi-gantry crane, which travels across the converter platform (*see* Fig. 11) takes over the scrap charging boxes shunted into the converter bay and transfers the scrap to the tilted converter. The same scrap supply system was used in planning work for The Steel Company of Wales, except that, instead of a semi-gantry crane, an overhead travelling crane operated on the same tracks as the hot-metal crane. However, two hot-metal cranes have to be provided where there are five and six converters, so that an additional crane to cater for the scrap supply would involve an overlapping of working fields. In other respects the steelworks is on the same plan as the plants already described.

Developments in the fourth stage may now be summarized:

(1) converters have attained a standard capacity of 50 to 60 tons,
(2) the casting car has been abandoned almost without exception and replaced by crosswise travelling steel transfer cars, which transport the steel ladles into the casting bay,
(3) casting takes place exclusively at casting stands set up along or across the bay,
(4) blowing with an air–oxygen or steam–oxygen mixture has become indispensable in improving the quality of steel and
(5) admixtures and cooling agents are charged into the converters by extensively mechanized processes.

So far only the bottom-blowing type of converter has been considered. A new process, called the LD process, has been developed during the last decade at the two Austrian steelworks, Voest in Linz and the Alpine-Montan-Gesellschaft in Donawitz, in which technically pure oxygen is blown on to the hot-metal bath in the converter through a water-cooled lance. The oxygen converter, too, is lined with tar dolomite bricks and has a closed bottom, in contrast to the basic Bessemer converter. The lance is positioned at a convenient height above the bath and blows oxygen on to and into the bath at a high rate. The method of working is similar to that used in the air-blowing process. Lime, cooling scrap, and molten pig iron are charged into the converter, the oxygen lance is introduced, and the oxygen supply turned on. During the blowing process cooling agents such as ore, scrap, and limestone chippings are charged through chutes into the blowing converter from the lime platform in order to control the slag and the temperature.

The converter nose of normal basic Bessemer converters is inclined to one side, so that the tilted converter can receive the heat without the tuyere bottom coming into contact with the bath of hot metal. There is no need for this in oxygen-blown converters as they have a closed bottom. It is therefore possible to choose a symmetrical shape of the converter which is more favourable for blowing.

A cross-section view of the lance-blowing converter plant at the Alpine-Montan-Gesellschaft in Donawitz is illustrated in Fig. 12. The layout differs from that of a normal basic Bessemer steelworks and it is possible to accommodate the converter centrally in a narrow stack aisle so that the charging operations can be carried out on one side and casting carried out on the other. Scrap as well as hot metal is charged. The finished steel is transferred by a crosswise travelling steel transfer car to within the working radius of the casting crane. At Donawitz the steel is cast at casting stands set up along the bay.

A lance carrier, in the form of a bracket crane, transports the vertically suspended, water-cooled lance along the bay, and, if the tuyere head has to

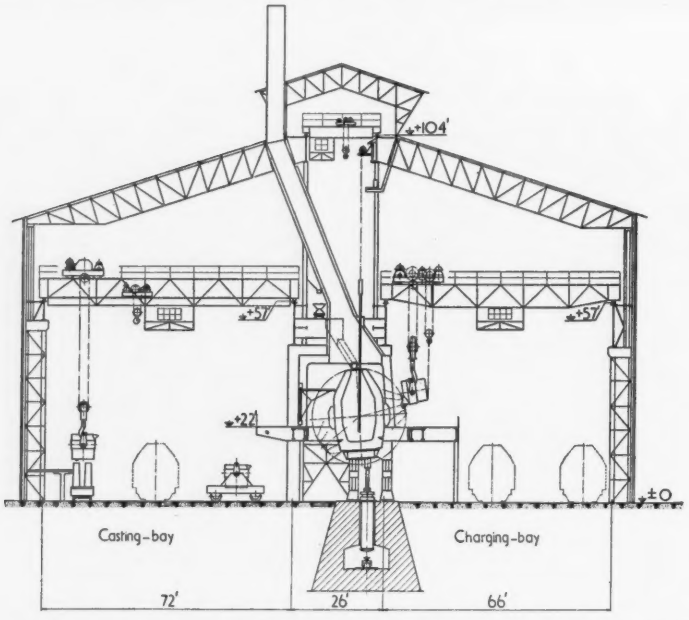


Fig. 12—Cross-section of the lance-blowing converter plant of the Alpine-Montan-Gesellschaft, Donawitz

be exchanged, the lance can be transported to its repair shop by an overhead travelling crane moving at an even higher level. The lance carrier has an electric hoist block by means of which the lance is introduced and withdrawn from converter. Each converter has two lances (including carriers with separate oxygen and cooling-water connections, as well as the necessary hoisting gear), so that blowing of the heat can immediately be taken over by the reserve lance if damage occurs to the first one.

The oxygen blowing process was developed for refining types of pig iron having a low phosphorus content, and attempts are being made to apply this process to the treatment of pig iron with higher phosphorus content.

CONVERTER SHAPES AND DESIGNS

The size of converters has increased rapidly in recent decades. When development work first started, units of 10 to 15 tons capacity were the rule; converter vessels with a capacity of 50 to 60 tons are now usual. Increasing the converter size to 80 tons may reduce operating costs still further and make the working procedure smoother.

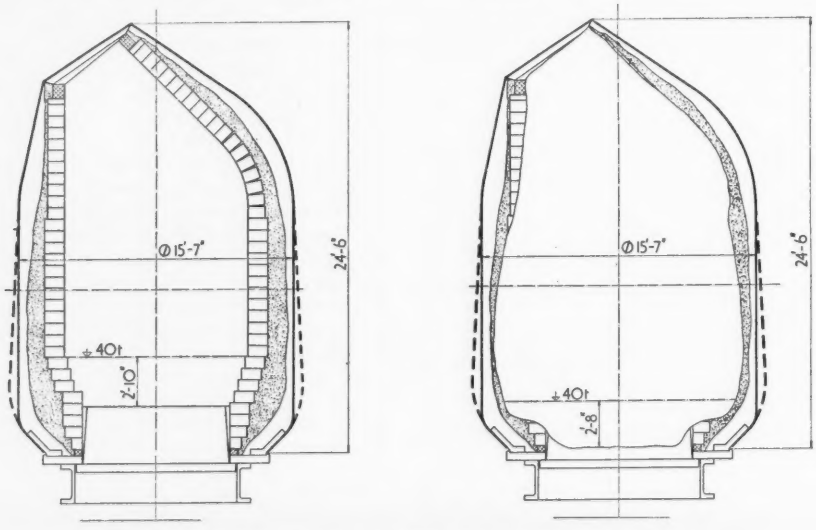


Fig. 13—A 40-ton converter in newly lined and burnt-out states

The shape of converter vessels must comply with flow engineering principles. Figure 13 shows a 40-ton converter in both newly-lined and burnt-out states. Following previous practice the shell of this converter is cylindrical. Burning through of the converter at those places where the lining is most exposed to wear can be prevented by giving the middle sections of the converter vessels a conical form coinciding with the burn-out curve, as is shown with a dotted line in Fig. 14. Thus, the converter vessel is so fashioned that it has its maximum internal diameter and the greatest thickness of its lining at the level of the metal surface, in the region where lining wear is at its greatest.

Figure 14 shows a 55-ton converter built on these principles. Its main measurements are:

Maximum internal diameter inside the plate shell approximately	18 ft 4 in.
Total height of the converter approximately	26 ft 8 in.
Height of level of the bath approximately	2 ft 11 in.
Distance from top of converter bottom to lower lip of mouth approximately	19 ft 7 in.
Volume of the converter approximately	1960 ft³
Surface area of the bath approximately	100 ft²
Cross-section area of the blast stream per ton of charge when air blast is employed approximately	2·5 in²
Thickness of lining at level of bath	3 ft 5½ in.
Diameter of bottom	9 ft 10 in.

The large surface area of the bath facilitates better reaction between the bath and the slag, and the low level of the bath helps to achieve a low nitrogen content in the steel. Using a large bottom allows a higher blast to be employed. This results in a shorter blowing time and consequently a longer service life of the lining. By choosing a suitable size for the converter top, sloppings are reduced to a minimum and the formation of skull obviated as much as possible.

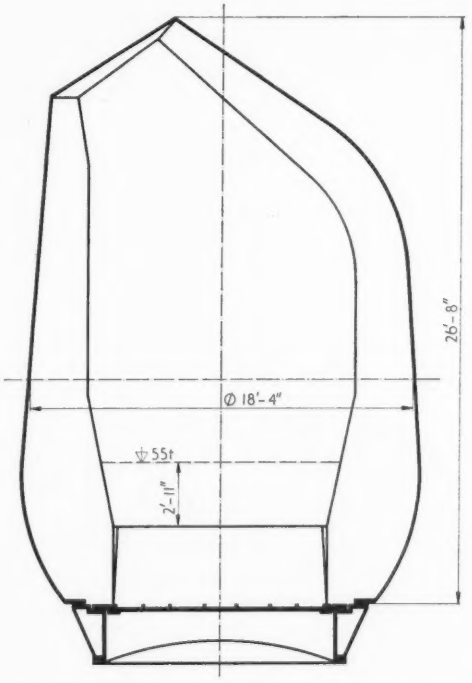


Fig. 14—Cross-section of a 55-ton converter having its maximum internal diameter and lining thickness at the level of the metal surface

Fig. 15—One of the 55-ton converters at the Salzgitter metallurgical works

Converter vessels are now welded rather than riveted as the riveting of the type of thick plate required for 50- and 60-ton converters offers considerable difficulties. Also riveted converters do not completely prevent the tar of the dolomite lining seeping out and burning on the external surface of the shell of the converter vessel. Through this escape of tar the dolomite lining becomes thinner and its durability is impaired. Welded vessels are completely satisfactory in this respect.

Figure 15 shows a 55-ton converter at the metallurgical plant of Salzgitter. It is supported by the heavy cast-steel ring through which the blast is brought to the blast box. One of the two connecting pipes can be seen at the lower right-hand edge of Fig. 16.

Figure 16 shows a welded converter vessel being assembled. The crane is lowering the already welded converter top on to the conical middle section, which is mounted so that it can be rotated.

The latest development in the field of converter construction is the ringless converter, shown in Fig. 17.

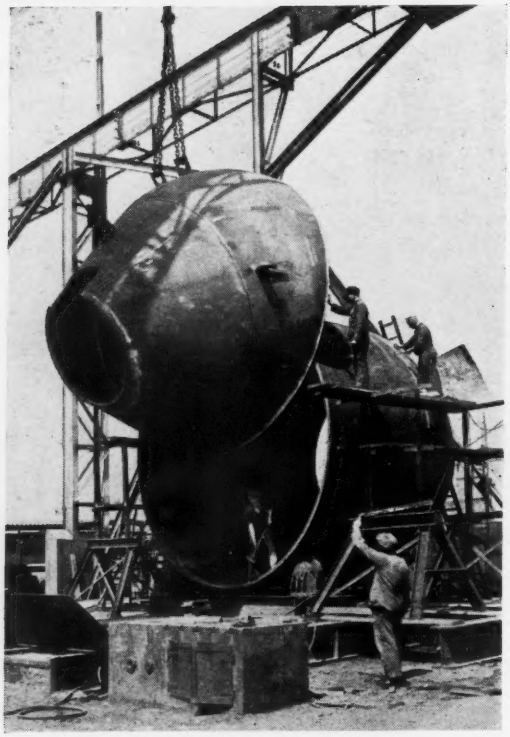


Fig. 16—Assembly of a welded converter vessel

This new design makes it possible to replace small converters by larger ones without having to vary the distance between the stands. The ringless converter has a reinforced centre section welded on to it, and the trunnions are screwed into this section. The transfer of heat from the vessel to the trunnions and bearings, which would be detrimental, is prevented by an air gap. Furthermore, it is possible to adjust and exchange the trunnions at any time, which may naturally be necessary when the converters are operated for many years.

THE CONVERTER TILTING DRIVE

While Bessemer converters have an electric drive, hydraulic tilting mechanisms have been adopted generally for basic Bessemer converters, as a great amount of pressure is necessary (after a slow approach) to press the nose down when skull is being forced off the mouth of the converter. This pressure can be attained only by the use of a hydraulic system. The first hydraulic tilting drives were designed for an operating pressure of 355–425 lb/in^2 (25–30 atm). The later increase in converter capacities brought with it simultaneously a corresponding increase of the water pressure to between 860 and 1000 lb/in^2 (60–70 atm). The pressure-water plant, originally designed with a weight accumulator, is now provided exclusively with a compressed air accumulator, in which the number of air cylinders used is chosen to keep the pressure drop within reasonable limits. The increase in the capacity of converters to 60 tons and more means that bigger cylinders and large-scale control apparatus are required, even if a water pressure between 860 and 1000 lb/in^2 (60–70 atm) is used. Also, substantial quantities of water have to be accelerated and slowed down rapidly. An operating pressure of 2850 lb/in^2 (200 atm) is often selected.

Whereas ring pistons are used almost exclusively when a medium operating pressure is chosen, plunger pistons are necessary for high-pressure plant, and slide valve gear is replaced by poppet valve gear. In order to locate the stuffing boxes of the cylinders above floor level, two plunger pistons with cylinders set up side by side are used, and each plunger is equipped with a rack. Between the two racks there is the pinion mounted on the trunnion so that when one of the racks moves upwards the rack opposite moves downwards, and vice versa.

The incorporation of a quick-acting safety valve, the function of which is to prevent the converter from getting into motion accidentally if the pressure water system or pipes fail, is a further improvement. This device ensures that water seals all cylinder spaces effectively and prevents the converter moving. A normal pressure-water plant, consisting of piston pumps and compressed-air accumulator, is used to compress the water. The electrical control apparatus switches the water pumps on and off according to the water level. The accumulator is large enough to ensure that those movements of the converter which are absolutely necessary to finish off the heat can be carried out if the electricity supply fails.

REGULATING SYSTEMS

Another important problem which has been solved in recent years is the regulation of the air–oxygen and steam–oxygen mixtures. The regulating system used for the oxygen-enriched air employed at Sollac's

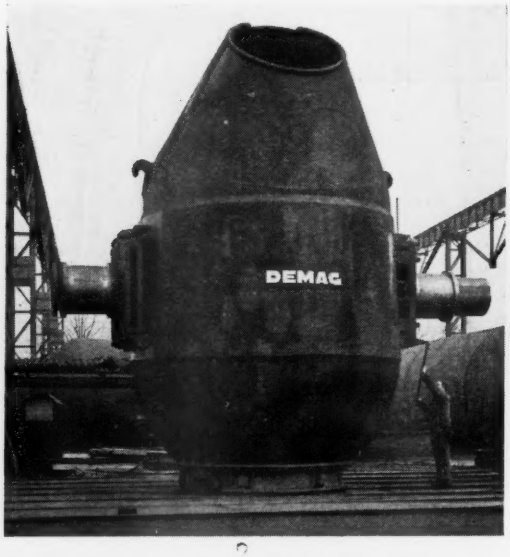


Fig. 17—A welded ringless converter

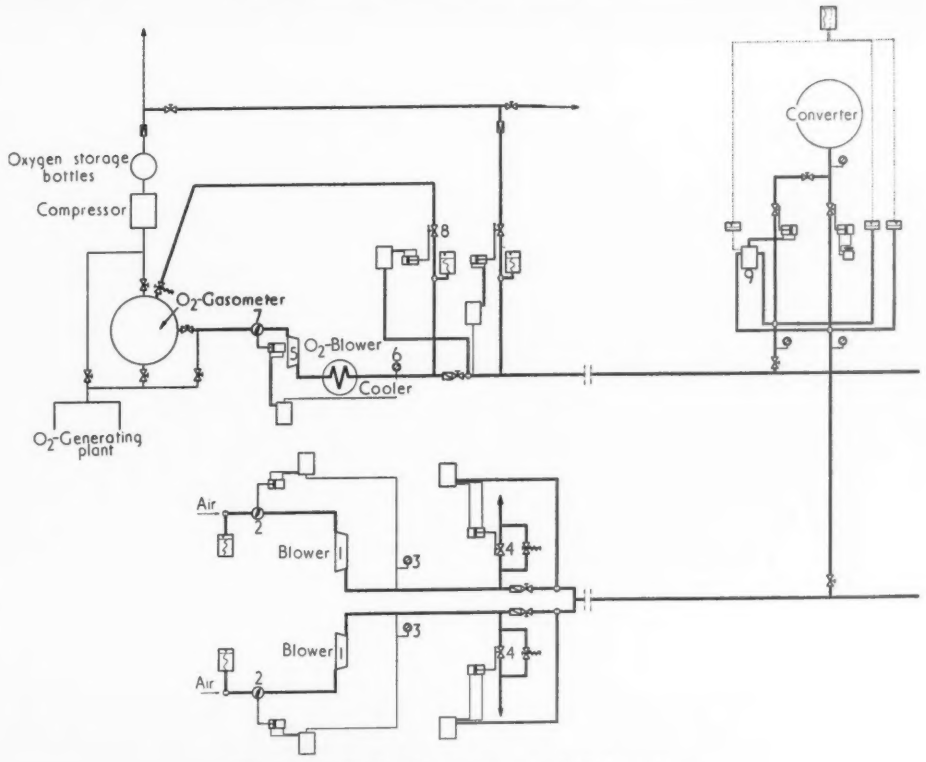


Fig. 18—Sollac's air-oxygen regulating system

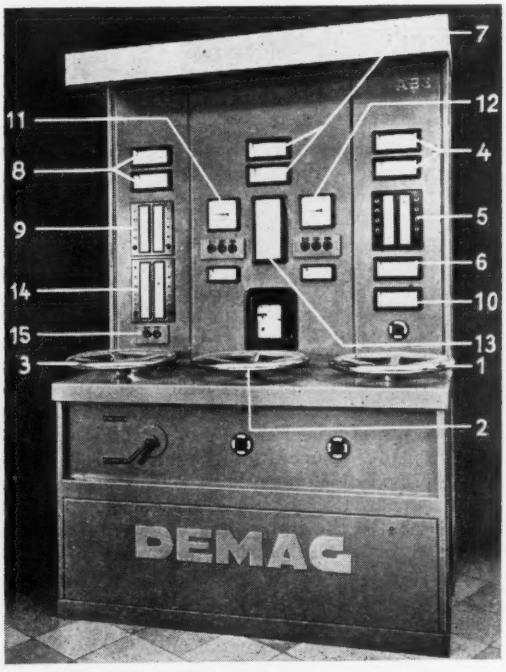


Fig. 19—Control stand for air-oxygen regulation

basic Bessemer steelworks is shown in Fig. 18. The air is generated in two turbo-blowers (1), which are arranged in parallel. The intake volume is controlled by throttle valves (2) set up behind the blower, and depends on the air pressure (3). If the quantity of air supplied to the converters falls below the surge limit of the blower, the regulating valves (4) of the blow-off pipes are opened automatically. The oxygen supply, which is withdrawn by a blower (5) from the gasometer, is regulated in the same way. In this case, too, the oxygen pressure (6) behind the blower controls the throttle valve (7) and thus regulates the intake volume.

Whereas, in the case of the air line, the quantity blown off—when there is a fall below the surge limit—is led off into the open air, in this case a circulation system is provided which leads back into the gasometer. The regulating valve (8) opens and closes independently of the quantities of oxygen taken off to the converters. To meet peak requirements, oxygen can be taken from storage cylinders and led into the main via reducing and regulating valves. Oxygen and air are brought as far as the converter valves under constant pressure, and the pressure level is varied only after they have been mixed. The automatic mixture regulator (9) makes it possible to keep the concentration of the mixture constant while the volume of blast is varied; this is imperative for continuous operation.

The converter control stand (*see* Fig. 19) has, from

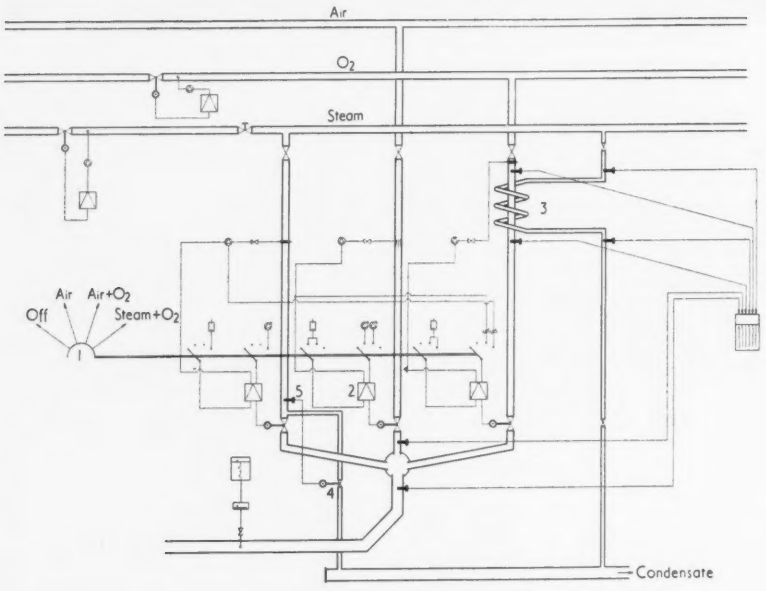


Fig. 20—Three-component regulating system for air-steam-oxygen

right to left, the handwheels for operating the hydraulically controlled air valve (1), the automatic mixture regulator (2), and the hydraulically controlled oxygen valve (3), the last of which need be operated only if the automatic control gear fails. The indicators for the air volume and pressure (4) are to be found on the right-hand panel of the control stand, with the group of control instruments (5) for the air blower below. Underneath this group there is the indicator for the blast temperature (6). The large variations in the blast temperature necessitate the provision of an automatic temperature regulation system. The indicators (7), which show the mixture concentration in terms of the ratio of oxygen to air as well as the mixture pressure, are located in the centre panel. The left-hand panel contains the indicators (8) showing the oxygen quantity and pressure, as well as the group of controls (9) for the oxygen blower. The temperature of the bath is measured with an immersion pyrometer connected up with the control stand. Its indicator (10) is on the right-hand panel below the air temperature indicator. In addition to the instruments mentioned above, the central panel of the control stand also contains indicators showing the quantities of limestone chippings and ore,[11, 12] as well as the push-buttons for releasing these materials. In the middle there is the pressure-water level indicator (13). The left-hand panel has, below the group of control instruments for the oxygen blower, already mentioned, the set of controls (14) for the scrap and lime platforms. The lime bin has a pneumatically controlled gate, which is also operated from the converter control stand (15).

Blowing with steam–oxygen mixtures confronts regulating techniques with special problems, as there must be a simple switch-over system available so that changes can be made from pure air to oxygen-enriched air and steam–oxygen mixtures. Moreover, a continuous transition must be ensured during the switching-over process, and no oxygen or steam peaks must be allowed to occur.

Figure 20 shows one such regulating system, with a selector switch (1), which has four positions; one for blowing with pure air, one for oxygen-enriched air, one for a steam–oxygen mixture, and one for when the plant is switched off When a switch-over is made from one position to the next, the valves involved in the lines are automatically opened and closed. The quantity of oxygen to be mixed with the air is controlled by an electronic regulator (2) (in proportion to the total quantity of air), depending on a predetermined target value. The oxygen supply, when a steam–oxygen mixture is used for blowing, is correspondingly dependent on the quantity of steam flowing through.

To avoid condensation of the steam in the wind box of the converter, it is necessary to heat up the oxygen so that the temperature of the steam–oxygen mixture, on entry into the wind box, is higher than the saturation temperature of steam at the operating pressure used. Steam is used for preheating the oxygen (3); at other plants recuperators heated by blast-furnace gas are provided. Condensate is formed in the steam line, if there are long periods of inactivity. To remove this condensate, the drain valve (4) of a discharge line is opened by a thermo-electric impulse when the temperature falls below that at which condensation takes place.

The control stand for this plant is shown in Fig. 21 at the bottom of which can be seen the selector switch for the four operating positions in addition to the push-button controls for the quantities of air, steam,

and the concentration of oxygen, arranged to correspond to the different operating positions. All other instruments on this stand are for measuring the pressure and quantities of the different components of the mixture. A large oxygen counter in the centre records the quantity of oxygen flowing through during the course of one heat.

TELPHER LINES

The transport of admixtures, such as lime, limestone chippings, ore, sand, anthracite, soda, etc., must be well planned if a converter plant is to run smoothly. A converter plant with six 50-ton converters requires a daily quantity of about 2000 tons of such materials to be brought up to the lime platform.

For plants built in recent years electric telpher systems have been chosen without exception, as these have a large capacity and offer the unrestricted possibility of bringing up the various materials in any sequence desired. The closed circuit of the electric telpher system runs under the central bins outside the steelworks, ascends an incline (where the buckets are caught up by a moving endless chain and disengaged automatically at the top end of the chain at the level of the lime platform) and passes over the converters to the dolomite plant to loop back subsequently to the central bins. The circulation of the buckets is controlled and supervised from a central control stand, which each bucket passes on its way round and where it is weighed. All electric points are controlled from this stand, as well as the stops over the bins on the lime platform. To control the distance between the individual cars on the circuit, and to prevent the cars piling up one against the other, the circuit is equipped with an automatic blocking system. A siding is provided on the lime platform, so that a certain reserve of filled cars is available if there is a breakdown.

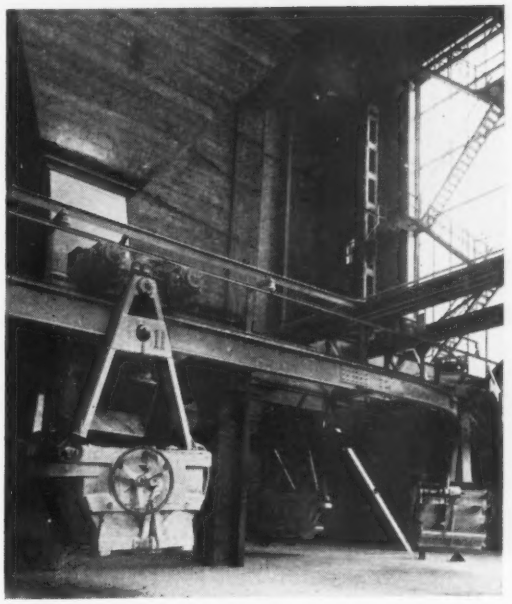


Fig. 22—Telpher car below the central bins

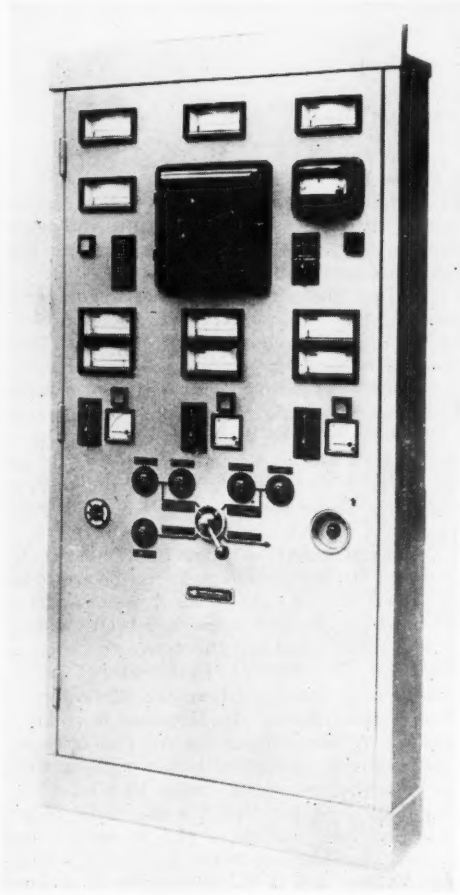


Fig. 21—Control stand for three-component regulation

A crew of two is necessary to operate this plant, one of whom looks after the control stand, while the other is responsible for the filling of the buckets at the central bins. Figure 22 illustrates one of the buckets which hold 35 ft³ (1 m³), on the telpher rail leading past the central bins. The bucket on the left has been stopped immediately under the bin outlet. The capacity of the plant is such that the daily transport of materials can be effected in 12 to 14 working hours.

THE DOLOMITE PLANT

The economics of a basic Bessemer steelworks is dependent to a considerable degree on the durability of the refractory lining of the converters. Thomas used a mixture of dolomite and tar, and the walls of converters are still made of tar dolomite bricks, or of a mixture which is rammed in. The tar dolomite bricks cannot be stored, as burned dolomite absorbs moisture and perishes. It is, therefore, necessary to produce these bricks in the neighbourhood of the

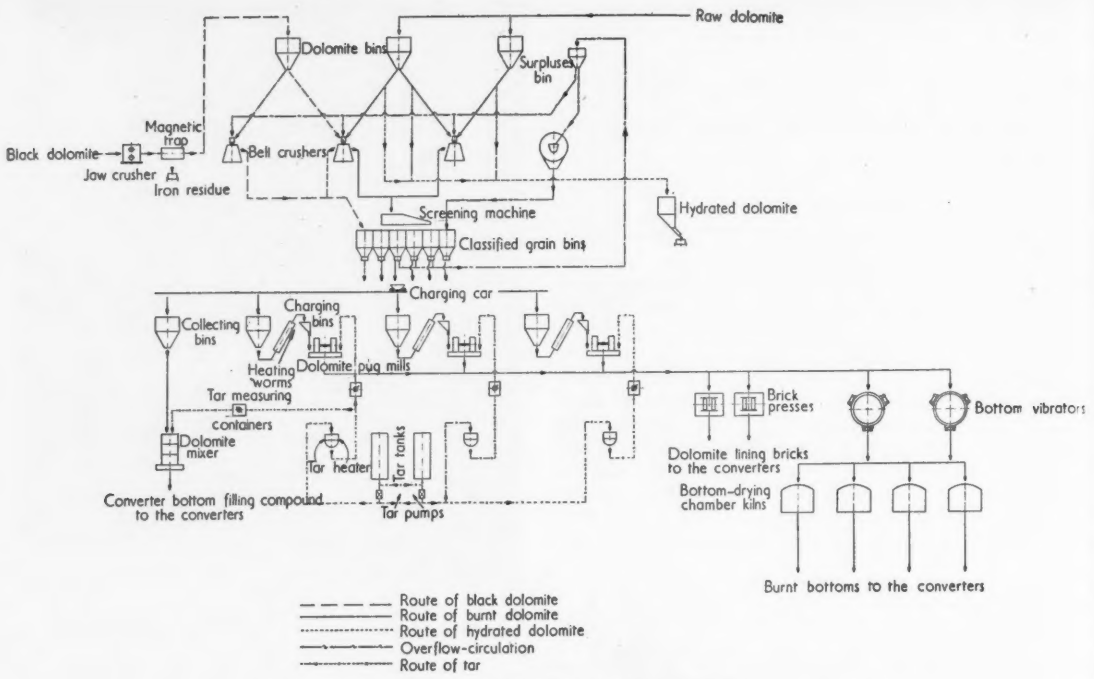


Fig. 23—Flow sheet of a dolomite plant

steelworks. Each basic Bessemer steelworks has its own dolomite plant equipped with grinding, screening, and sorting plants and all machinery necessary to produce the refractory bricks and ramming material. Particular importance must be attached to efficient screening, as the durability of the converter bottoms and of the lining depends on the texture of the refractory material being as close as possible; it should contain a high percentage of coarse grains.

Figure 23 represents the flow sheet of a modern plant. The burnt dolomite is transferred from its bins to the bell crushers, which pass on the ground material to a screener. From here the material, which has been sorted according to its grain size, is conveyed to the classified grain bins. Hydrated components of the dolomite are sifted out before the bell crushers are reached. The excess grain material leaves the classified grain bins through an overflow and is led off to a ball mill, via an intermediate bin. Here the material is ground down further to a powder. Salvaged converter linings can also be used in the manufacture of bricks. Such material is taken to a bell crusher, after having been processed by a jaw crusher and a magnetic drum, and is deposited in an intermediate storage bin. It is ground at the bell crusher and collected in another bin; no assorting being necessary.

A charging car, equipped with scales, removes set quantities of dolomite of a definite grain size from the classified grain bins, together with the ground-up used converter lining material, and charges the bins in front of the pug mills. In this way quantities charged can be adjusted exactly. The pug mills themselves are charged after the materials have passed through heating coils, in which the dolomite is warmed up. The tar is pumped into the pug mills from large tar tanks, after passing through heaters and volumeters. The further processing of the ground and mixed tar dolomite mass takes place in the brick presses and the vibrators. The dolomite mixer produces the filling compound put in the space between the new converter bottom and the lining.

Figure 24 shows the ground plan, a cross-section, and longitudinal section through the plant planned for The Steel Company of Wales Ltd. In the top right-hand corner of the cross-sectional view is the rail of the monorail trolley which brings the dolomite to the storage bins. Below the bins there are the bell crusher and ball mill, while under these is the assorting plant. Pug mills and dolomite mixer plant are located at floor level. On the ground plan can be seen the two brick presses, to the right of which there is the sheet-metal-lined pit, where the finished bricks are stored.

It is planned to shake the converter bottoms by means of vibrators attached to the sides of the bottom moulds. This has the advantage of uniform compaction of the bottom. Gas liberated from the tar is driven out by intermediate heating and by repetition of the vibrating operation which reduces the pore space in the bottom and increases its service life. On the right of the ground plan is the preheating plant for intermediate heating of the vibrated converter bottoms. The kilns where the bottoms are burnt are set in the long wall of the bay, facing this plant. In these kilns five bottoms at a time are burnt for about ten days. At the right-hand gable end are the runways

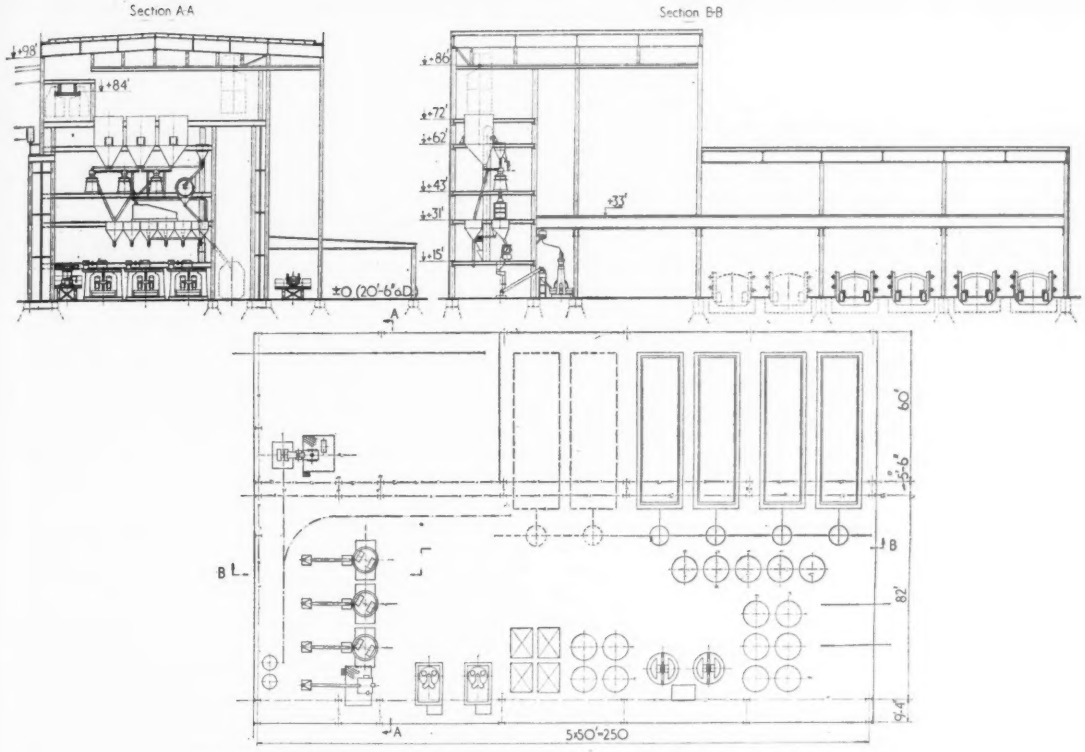


Fig. 24—Dolomite plant planned for The Steel Company of Wales, Ltd.

for the bottom handling trolley which brings the finished bottoms under the converters.

THE SLAG TREATMENT PLANT

An important by-product of the basic Bessemer process is the basic Bessemer slag, which, when ground to powder, is used in agriculture as a fertilizer with high phosphorus content. The ground plan of a slag treatment plant being designed at the present time is shown in Fig. 25. At the bottom can be seen the large slag yard on which the slag coming from the basic Bessemer steelworks is stored for about 6–8 weeks. The breaking down of the slag proceeds uniformly and it cools sufficiently as a result of the

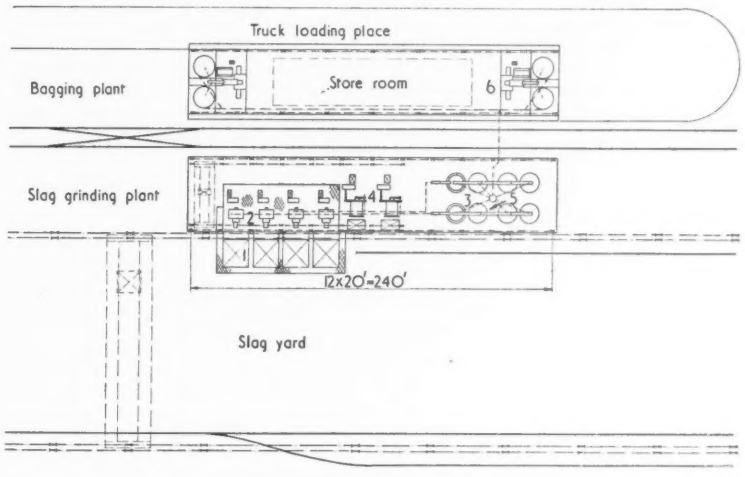


Fig. 25—Layout of a slag treatment plant

weathering. An excavator working on the slag dump turns over continually the slag which is being weathered and sorts out iron inclusions and skull which may be present. At the same time it fills buckets which are available there for transport purposes with well-seasoned, well broken-down slag. An overhead travelling crane conveys these buckets over the grinding plant bins used to store materials prior to treatment, where they are then emptied by a process which keeps the creation of dust to a minimum. The slag is brought up to the ball mills (2) from these bins via a magnetic separator. From the mills it is conveyed through a dust-proof transport system via air separators into the powder storage bins (3). The air separators sort out any remaining material which is still coarse, and return this (via downspouts and worm conveyors) to the tube mills, which process this also to powder. The storage bins are fitted with an automatic homogenizer plant which blows jets of compressed air through the bottom of the bins to keep the powder continuously mixed. Double worm conveyors remove the powder from the storage bin as it is required and send it to the packing plant through a pneumatic conveyor (5). The packing machines (6) are semi-automatic and fill the powder into sacks. These are conveyed either to the store-room by belt or directly on to the loading ramps, where they are loaded into railway trucks and lorries. Grinding and packing equipment is kept entirely free from dust by the installation of dust-arresting plant, and the ground material is not exposed to the open air from when it enters the storage bins before it is handled until it is packed into sacks.

WASTE-GAS PURIFYING PLANT

The use of an oxygen-enriched air blast in converters—and the increasing pollution of the atmosphere by converter exhaust gases, which it entails—make the installation of a waste-gas purifying plant desirable. Particular difficulties are associated with the development of such plant as the incidence of such waste gases is periodic, while, at the same time, they have a very high temperature (about 1700° C). During experiments lasting over many years it has been found that the gases can be cleansed of dust economically only if the high heat content of the waste gases is used to produce steam. This dispenses with any cooling plant, which would have to be set up in front of the purifying plant (and which would occasion high operating costs because of the constant need for cooling water). Moreover, if a cooling plant were used, the temperatures after cooling would still be so high that the flue would have to be given a lining or be cooled with water itself.

The first waste-gas purifying plant was built for oxygen-blowing converters, as in their case there are few, if any, sloppings in comparison with bottom-blowing converters, and the quantities of waste gas are significantly smaller. To utilize the thermal energy a waste-heat boiler was included and a de-duster installed behind it. Such plant disposes of 98–99% of the dust—a degree of efficiency which satisfies the existing regulations in many countries.

The most suitable waste-heat boiler is a forced-circulation boiler owing to the variations in temperature occasioned by the operation of the converters. Superheating temperature and pressure of the steam produced in this boiler can easily be adapted to the operating conditions of the steam system existing in the metallurgical works. In order to have the steam boiler working continuously in spite of the periodic nature of the supply of dust-bearing gas, an additional blast-furnace gas heating system can be included to take over when the heat is ended.

Waste-gas purifying plant for basic Bessemer steelworks is still being developed. At present various systems are being tried with pilot plants and a full-scale operational plant may be built shortly.

The dust precipitated in the de-duster can be recovered from the sediment in a settling plant, mixed with blast-furnace gas or roasting kiln dust, and then granulated or briquetted for charging into the blast furnace.

INVESTMENT COSTS

A modern basic Bessemer steelworks with an annual capacity of about 1 million tons of crude steel requires now an investment of about £6·8 million when the auxiliary plant is taken into consideration. For an O.H. steelworks the building costs will be 35–40% higher, all other conditions being equal. This comparison is naturally only approximate, as a study of local circumstances and the production programme need to be taken into account.

PROSPECTS

Work on developing the process will be carried on vigorously. The most urgent task—an improvement in quality—demands more investigation of the use of oxygen and protective gases and also the most suitable shape of the conversion vessel.

Mechanization of working procedure will also claim much attention, particularly as future steelworks for large-scale production will have annual outputs ranging from 1·5 to 2 million tons of crude steel.

Acknowledgments

The illustrations used in this paper have been made available by kind permission of the following firms:

Fig. 1: Phoenix-Rheinrohr A.G., Vereinigte Hütten- und Röhrenwerke, Düsseldorf.

Figs. 2 to 19 and 22 to 25: Demag Aktiengesellschaft, Duisburg.

Figs. 20 and 21: Hartmann und Braun A.G., Frankfurt/Main.

Discussion

Mr. **H. F. Padbury** (Richard Thomas and Baldwins Ltd., Ebbw Vale): As one of the small number of people actively engaged in the Thomas process, I find it very encouraging that the Iron and Steel Engineers' Group should turn to consideration of the basic Bessemer process. Dr. Herrmann has given a masterly survey of the developments of the process and a very clear picture of modern plant design.

I consider that, in this country at least, it is the development of new blowing techniques, using oxygen, that has made the process of such interest to people concerned in the flat rolled products section of the steel industry. These developments have enabled a steel of the very highest quality to be made in the basic Bessemer converter. In my opinion, the oxygen–steam process is only an intermediate process which will eventually be superseded by a top blowing process for high phosphoric iron, as suggested by Dr. Herrmann.

In his reference to the plant installation at The Steel Company of Wales he said that the quality required that the blowing practice be based on an oxygen–steam mixture. I was not able to gather whether an air supply will be available and whether a minimum proportion would be blown with oxygen-enriched air.

I notice that Dr. Herrmann proposes very high pressure water—200 atm—and then goes on to refer to poppet valve gear. We use poppet control valves, but I am rather uneasy about this type of valve because it does cause terrific build-up of back pressure in the hydraulic system if operated roughly. Possibly Dr. Herrmann has some control which can eliminate that. In our experience, shock on the hydraulic system is a very serious factor.

Neck cleaning of converters is a very difficult problem. There has been little or no development in the technique over possibly 40 or 50 years. I shall be pleased to know what steps Dr. Herrmann proposes to take to improve neck cleaning methods in his new installations.

In any basic Bessemer plant, the success of the operation depends on continuity, uniform bottom life and uniform lining life. Uniformity of operation is undoubtedly made in the dolomite shop. I am thoroughly in agreement with Dr. Herrmann's ideas and proposals for sizing the dolomite and mixing fixed proportions of the various size ranges, the normal procedure used by the refractory brick makers. On the other hand, it is interesting to note that when the Western European Steel Community issued a questionnaire on this matter, they found that the great majority of people did not use this particular advanced technique, although some of them were getting remarkable results on run-of-the-mill dolomite.

Referring to our own experience at Ebbw Vale, I cannot agree with Dr. Herrmann when he says that one needs the maximum amount of the larger sizes. Our own experience indicates that we need a finely crushed dolomite, and basically our mixture is made up at about one-third from $\frac{3}{4}$-in. to $\frac{3}{8}$-in. down; one-third from $\frac{3}{8}$-in. to $\frac{1}{16}$-in. down; and one-third from $\frac{1}{16}$-in. down to dust. We have found that bell mills, such as Dr. Herrmann suggests in all his lay-outs, are not a suitable type of crusher for producing such fine dolomite. The cost for grinding plates and general maintenance on bell mills is enormous if you wish to make finely crushed dolomite, and we now intend to try hammer crushers.

Dr. **C. Herrmann**: I should not like to be so optimistic about the future development of the top-blowing process for high phosphoric iron. The trials carried out at the Mannesmann steel plant in Huckingen prove its technical feasibility, but the economics of the process need careful study.

The results obtained with the rotating converter developed in Domnarvet, Sweden, by Professor Kalling seem to be encouraging. In Germany the Oberhausen steel plant has developed a new process—the rotor process—for the treatment of high phosphoric iron. This is carried out in a long rotating furnace about 14 m long, and Dr. Graef will report on it next month before the gathering organized by the iron and steel industry in Düsseldorf. Oxygen is used in both processes, being blown into the bath in the case of the Kalling converter and on to the bath in the case of the Oberhausen rotating furnace.

The question as to whether an air blower is necessary when an oxygen–steam mixture is used in the basic Bessemer converter cannot be answered at present with a clear yes or no. In Luxembourg, Belgium, and Germany oxygen–steam mixtures are used, but not in the case of all charges, so that this question raises an entirely new problem which is now being investigated.

Operating at high pressures, in the region of 200 atm, valve gear for pressure-water systems has proved very satisfactory. Shocks occur principally if, instead of ball valves with throttle attachment, quite normal poppet valves or, indeed, dual poppet valves are used. Moreover, the way the pipes are laid and the rate of flow have some effect. If weight accumulators are used a 200% increase in pressure can occur if the valves are closed quickly, as a consequence of the sluggishness of

the weight box. The air accumulator, with its soft elastic qualities, can reduce this effect.

Very large forces develop in neck cleaning and so far attempts to produce a really successful machine have not succeeded. However, a piece of equipment employed by Arbed, Belval (Luxembourg), is worth mentioning. This involves a burner running in a circular guide by means of which the scull is burnt out.

Bell mills are employed almost universally in our basic Bessemer steel plants as the desired assortment of grain sizes can be obtained with them. Hammer crushers, on the other hand, yield only a coarse and fine grain but no intermediate product. The so-called 'dolomite meal' is obtained from a ball mill. The change of grinding plates involved in bell mills—these plates being made of chilled castings—is necessary only every three months. To obtain a favourable grain mixture the proportion of coarse grains should, indeed, be as high as possible, but it is necessary for these coarse grains to be completely embedded in finely crushed dolomite. Herr Metz published an interesting commentary on this matter in *Stahl und Eisen* (1954, pp. 10–24).

Mr. **A. E. Desoer** (S.A. Cockerill-Ougrée, Belgium): I should like to refer to the practice used for making the bottom of basic Bessemer converters. As stated by Mr. Herrmann, the bottoms are made of a mixture of burnt dolomite, previously ground in a rotary grinder, and heated tar, which is either rammed, shaken, or vibrated in a mould. The crude bottoms obtained in this manner are generally fired and baked in ovens of various types before being placed in the converter. The baking operation generally lasts from 6 to 8 days.

The durability of the bottom is a matter of concern for Bessemer basic operation as the availability of a converter, and therefore its annual capacity of production, is a function of the number of heats which can be made on a bottom and on a lining of the vessel. For converters of the same size, the average life of bottoms is apt to vary considerably from work to work, and in the same work, from period to period.

Considerable research work has been undertaken in all countries using the process, and lately on an international scale, to determine the effect of the factors involved and to improve bottom life. These researches have led to a good deal of success.

Besides the metallurgical factors such as pig iron analysis and blowing techniques, the quality of materials used for making the bottoms is of great importance. According to the quality of the dolomite mined, and the practice used in the burning kilns, the hardness of dolomite may vary considerably, as does the granular nature of the burnt dolomite issuing from the grinder. To make conditions as regular as possible, it has been found very advisable to use a mixture of dolomite grains of different sizes in exact proportions so as to achieve a good granular mixture. The modern trend, which has proved economical, is to install in the dolomite plan a complete sizing and grading plant.

As the cost of equipment and operation of the furnaces used for burning the bottoms is high, crude bottoms have been tried and tests have proved that with bottoms constituted with magnesite tuyeres or copper tubes according to a German patent, it is possible in small converters to avoid baking the bottoms.

The bottom is placed in the converter in the crude form and baked in the converter with a specially devised burner. Besides the saving achieved on the bottom manufacture we found in our works that, with 17-ton converters, the durability of the bottoms was improved. I would like to know if a similar practice has been used on 50- to 60-ton converters and with what degree of success. Can Dr. Herrmann give any answer to this question?

Dr. **Herrmann**: The process of working with green bottoms has been developed in recent months, above all by Cockerill-Ougrée. No experience has been obtained in working with large bottoms, but trials with bottoms for 30-ton converters are to be carried out in Germany in the near future. The diameter of the bottom for a 50-ton converter is about 10 ft and much experience will have to be acquired to extend the process to bottoms of this size.

Mr. **P. J. Leroy** (Institut des Recherches de la Sidérurgie (France)): I should like to ask Dr. Herrmann three questions on his very interesting paper. Does he think that in the future the riveted converter vessel will be completely given up and replaced by welded vessels; will the trunnion-rings gradually disappear? Secondly, is there in Germany, as in France and Luxembourg, a tendency to approve bottoms and wind boxes larger than formerly? Thirdly, do you sometimes propose an oval shape to steelworks which have to increase vessel capacity without changing the distance between both trunnions?

Dr. **Herrmann**: The riveted converter is nowadays being replaced almost universally by the welded converter. The so-called ringless converter is now being built by us up to a capacity of 50 tons. To date nineteen units altogether have been built or are in the course of construction. At present we are working on new plans to build ringless converters of up to 70 tons and more as well. The difficulties involved are principally a matter of taking up the forces which arise when skull is being removed and of providing the right thermal insulation of the converter trunnions.

The converter bottom has been enlarged in recent years, but the relationship which exists between this and the internal diameter of the converter, as can be seen from Fig. 14, has not been exceeded, since in our opinion a still larger bottom would involve a less smooth blow.

Prof. **H. O'Neill** (University College, Swansea): It is thrilling to find the basic Bessemer process returning to this part of South Wales. One of the minor factors hitherto given for its disappearance from Britain was the amount of metal wasted by projection from the mouth of the converter. I should like to know whether there are any modern methods for recovering such metal. I remember that 30 years ago in Lorraine some Bessemer plants were equipped with separators for recovering the metal, but I do not think Dr. Herrmann mentioned this point in connection with the new plant.

Dr. **Herrmann**: To my knowledge new methods have not been developed. The converter sloppings from the stack are treated in separators. The coarse material is charged into the converter or the blast-furnace, and fines as well as the roof dust are led off to the blast-furnace on the sinter belt.

The Chairman: I should like to ask a question of a similar nature. Has Dr. Herrmann any figures of the amount of dust emission from the various processes?

Dr. **Herrmann**: At one of Germany's basic Bessemer plants the quantity of sloppings per ton of crude steel was 12–17 kg, depending on the suitability of the hot metal for blowing. In addition the dust emission worked out at about 4·5 kg per ton of crude steel.

Sloppings and dust at a converter steel plant work out altogether at about 12 to 16 kg per ton of crude steel.

Mr. **J. S. Caswell** (University of Wales): Forty years ago the blowing plant at the old Ebbw Vale steelworks comprised a steam turbine and a multi-stage centrifugal blower. Since then there have been important developments in prime movers and blowing plant. In the new blast furnace plant at Margam, a steam, turbo-driven, multi-stage axial blower is being used. With the availability of coke-oven and blast-furnace gas and the high efficiency of modern gas turbines, a combination of this type of prime mover and an axial type blower appears to have attractive possibilities in Bessemer and blast-furnace plants. It would be of interest to have the author's views on the matter.

Dr. **Herrmann:** The use of a gas turbine as a prime mover connected up to an axial-type blower is worth consideration. For an axial blower, however, the minimum quantity of blast involved would have to be around 50,000 standard m^3/h, which is the case for converters above 40-tons capacity. Unfortunately the surge limit of an axial blower is about 80% of output (about 50% in the case of the radial blower); thus the speed of revolution of the turbine would have to be considerably reduced in the interval between two charges. It would, therefore, be preferable to employ a return expansion turbine for the blast. As far as I know the combination of a gas turbine and axial blower has not been tried out yet at a basic Bessemer steelplant.

CORRESPONDENCE

Mr. **R. T. Mitchell** (Richard Thomas and Baldwins Ltd.): Dr. Herrmann mentioned the vibration of converter bottoms by vibrators attached to the periphery of the bottom mould. This I know is done by rotary, out-of-balance, machines. Present moulds are some 3 in. thick and possibly more for large bottoms; this thickness would considerably dampen the vibrating effect before reaching the mixture in the mould. The consolidation of the mixture has a considerable effect on bottom life which becomes increasingly important when blowing with oxygen–steam mixtures. Has Dr. Herrmann any knowledge of vibrating with electromagnetic type units? I would suggest a vibrating table upon which the tuyere plate and side mould are placed, the whole of this dead weight being carried on springs; the vibrator required would vibrate the mixture with little vibration loss. A further advantage would be the elimination of trailing cables, and the necessity of fixing and removing the vibrator units.

Does Dr. Herrmann know whether the cubical product produced with a hammer mill possesses better binding qualities than the ' rolled ' product from the bell mill?

Could he suggest an alternative method of mixing slurry for the bottom joint to the usual screw-type kneader?

Dr. Herrmann described the instrumentation of an oxygen-enriched air installation and mentioned that the temperature of the blast was indicated. Is there any necessity for this, apart from obtaining the correction factor for volumetric measurement, or does it only apply, as required, when blowing with a steam–oxygen blast?

Dr. **Herrmann:** The arrangement of the vibrator proposed by Mr. Mitchell is used in one of the French steelworks for small bottoms about $5\frac{1}{4}$ ft in diameter. The arrangement of three vibrators attached to the periphery of the bottom mould, which I mentioned in my lecture, is employed in the two Luxembourg steelworks of Arbed in Belval and Düdelingen, as well as in Haspe and Huckingen in Germany. In Huckingen, indeed, bottoms with a diameter of 8 ft are treated. Very satisfactory operating results have been obtained.

The dolomite grains from the bell mill have sufficiently sharp edges to give good binding qualities. I have no data about experience obtained with dolomite grains produced in the hammer mill.

The screw-type kneader has proved very satisfactory in practice and is used almost universally on the Continent.

As Mr. Mitchell suggests, the blast temperature is measured only to obtain the correcting factor for volumetric measuring instruments.

Mr. **K. Bose:** Dr. Herrmann has compared estimates of the costs of open hearths and basic converters for an annual capacity of 1 million tons. Could he compare costs of the LD process with those of basic converters for the same capacity? Could he also comment on the effect on production of desiliconizing the hot metal prior to charging the metal in the converter?

Dr. **Herrmann:** The investment costs for a top-blowing plant with an annual production of 1 million tons amount to around £7·5 million, this estimate including the oxygen plant and the indispensable waste-gas purifying plant.

A desiliconizing plant gives the advantage of a higher output (up to about 10%) with hot metals containing a high percentage of silicon, as they become more suitable for blowing. A somewhat higher yield of steel is obtained also, as a smaller admixture of lime results in less slag.

As operating costs involved in desiliconizing are not insignificant, only a comparative cost calculation made in each particular case will elucidate whether the installation of plant is worth while.

Meeting of Junior Engineers, 1957

A meeting of Junior Engineers will be held at Chester and Manchester from Monday to Thursday, 11th to 14th March, 1957. The object of the Meeting is to provide an opportunity for the younger engineers and operators in the iron and steel and associated industries to discuss engineering problems and visit works of interest: any Members of the iron and steel and associated industries will be welcome at the Meeting provided they are below the age of 35, whether they are Members of The Iron and Steel Institute or not.

PROGRAMME

Monday, 11th March, 1957. 6.0 to 7.30 p.m.

Discussion at the Grosvenor Hotel, Chester, on developments at the Shotton Works of John Summers & Sons Ltd. A short introductory talk will be given by Mr. J. F. R. Jones, followed by informal technical discussions with the engineering staff of the Company.

Tuesday, 12th March, 1957

All day. Visit to the Shotton Works of John Summers & Sons Ltd.

7.0 p.m. Reception and Dinner at the Grosvenor Hotel, Chester, by invitation of John Summers & Sons Ltd.

Wednesday, 13th March, 1957. All day

Visit to the works of Metropolitan-Vickers Electrical Co. Ltd. at Trafford Park, Manchester.

Thursday, 14th March, 1957. 10.0 to 12 noon

Lecture at the Grosvenor Hotel, Chester, on " Engineering Problems in Nuclear Power Stations " by S. A. Ghalib, Chief Engineer, A.E.I.—John Thompson Nuclear Energy Co. Ltd., followed by a film on the Calder Hall Nuclear Power Station and by discussion.

N E W S

Announcements and News of Science and Industry

NEW YEAR HONOURS

G.B.E.

Sir **Archibald Forbes,** Chairman of the Iron and Steel Board.

C.B.E.

Dr. **A. T. Green,** Director of the British Ceramic Research Association.

Mr. **O. W. Humphreys,** Director of the G.E.C. Research Laboratories.

O.B.E.

Mr. **W. Barr** (*Honorary Treasurer*), Technical Director, Colvilles Ltd.

M.B.E.

Miss **M. K. Walshaw,** Thos. Firth and John Brown Ltd.

NEWS OF MEMBERS

The **President** (Dr. H. H. Burton, C.B.E.) has been elected an Honorary Member of the South African Institute of Mining and Metallurgy for 1956/1957.

Dr. **William Bleloch** has been elected President of the South African Institute of Mining and Metallurgy for the 1956/57 Session.

Dr. **H. S. Blumberg** is now Consulting Metallurgist to the M. W. Kellogg Company, New York.

Mr. **W. J. Burrill** has resigned his position at the Ministry of Supply Royal Ordnance Factory, Birtley, Co. Durham, and has taken up an appointment with Imperial Chemical Industries Ltd. (Metals Division), Summerfield Research Station, Kidderminster.

Dr. **Maurice Cook** has been awarded the Institute of Metals (Platinum) Medal for 1957.

Mr. **T. R. Craig,** O.B.E., has been appointed a representative of the British Coking Industry Association to the British Tar Federation.

Mr. **H. E. Dixon** has resigned his position as Chief Metallurgist with the British Welding Research Association to join Richardsons, Westgarth Atomic Ltd.

Mr. **T. Fitzgerald** has left the Defence Standards Laboratories, Ascot Vale, Victoria, Australia, to take up an appointment as Assistant Metallurgist to the Electricity Commission of New South Wales.

Mr. **E. T. Gill** has joined the Mond Nickel Co., Ltd., in the Development and Research Department as Development Officer for constructional alloy steels.

Dr. **L. T. M. Gray** has been appointed a part-time member of the Monopolies Commission.

Mr. **H. A. Halupka** is now Mill Superintendent at the Hilton Mines, Shawville, Quebec, Canada.

Dr. **H. K. Hardy** has been awarded the Rosenhain Medals of the Institute of Metals for 1957.

Mr. **J. O. Hilliard** has joined the Companhia Siderurgica Nacional, Volta Redonda, Brazil, as Blast Furnace Consultant.

Mr. **P. T. Houldcroft** has been appointed Chief Metallurgist of the British Welding Research Association.

Dr. **D. Johnston,** formerly Head of Metallurgy at the County Technical College, Wednesbury, is now with Ever-Ready Razor Products Ltd., Glasgow.

Mr. **H. D. Jones** has left the Round Oak Steelworks Ltd. to take up a post as Lecturer in Metallurgy at the County Technical College, Wednesbury.

Mr. **D. H. Kyle** has been appointed a director of the Bamburgh Shipping Company.

Sir **Andrew McCance,** F.R.S., succeeded Sir Ernest Lever as President of the British Iron and Steel Federation on 1st January, 1957.

Professor **J. M. Otero,** formerly Director of the Spanish Naval Research Laboratory, has been appointed Vice-President and General Manager of the Spanish Nuclear Energy Board.

Mr. **T. Powell** has been appointed Managing Director of Lomas British Acheson Electrodes Ltd. He will remain a director of Union Carbide Ltd. and Divisional Managing Director of the British Electro Metallurgical Co., Ltd.

Mr. **A. G. Prentice** has left the South Durham Steel and Iron Co., Ltd., to take up a position with Bairds and Scottish Steel Ltd.

Mr. **A. O. Schaefer** is now President of the Pencoyd Steel and Forge Corporation, Philadelphia.

Mr. **D. Somerville** has resigned his position as Assistant Melting Shop Manager with the Consett Iron Co., Ltd., to become Assistant Manager at the Mavilbank Works of Smith and McLean Ltd., Glasgow.

Mr. **R. Staton** has been appointed a director of Firth-Vickers Stainless Steels Ltd.

Mr. **Gerald Steel,** C.B.E., has been appointed President-elect of the British Iron and Steel Federation for 1957.

Mr. **G. E. Tanner** has left the South Durham Steel and Iron Co., Ltd., to take up a position as Senior Technical Officer with Imperial Chemical Industries Ltd. (Metals Division), at Witton, Birmingham.

Mr. **Reginald Tate** has left Trans-Canada Airlines to take up the position of Materials and Processes Engineer with Canadian Pacific Airlines in Vancouver.

Mr. **J. L. Tatman** is now associated with Ramseyer and Miller Inc., New York, and will be in India for the next 18 months.

Mr. **C. R. Wheeler,** C.B.E., has been appointed a director of the Bamburgh Shipping Company.

Mr. **C. H. Wilson** has been appointed a director of Cochranes (Middlesbro) Foundry Ltd.; he retains the position of General Manager of the Company.

Obituary

Mr. **Malcolm Brown** (*elected* 1936), of Henley-on-Thames, on 14th November, 1956.

Mr. **James Sinclair Kerr** (*elected* 1911; *Vice-President*), on 14th December, 1956.

Mr. **Charles Francis Ramseyer,** A.B., M.S. (*elected* 1930), of New York, on 9th December, 1956.

CONTRIBUTORS TO THE JOURNAL

C. Bodsworth, M.MET., A.I.M.—Lecturer in Metallurgy, University of Liverpool.

Mr. Bodsworth was educated at Firth Park Grammar

A. G. Grimshaw

C. Herrmann

T. G. Macfarlane

J. W. Midgley

School, and spent four years with The United Steel Companies Ltd., serving an industrial apprenticeship; most of this time was spent with Samuel Fox and Co., Ltd. After service with H.M. Forces, he undertook full-time studies at Sheffield University. He was awarded the degree of B.Met. and the Mappin Medal in 1950, and became M.Met. the following year. Mr. Bodsworth was appointed to his present position in 1953.

P. T. Carter, B.SC., PH.D., F.I.M.—Senior Lecturer in Metallurgy, Royal College of Science and Technology, Glasgow.

Dr. Carter was born in Middlesbrough and educated at Middlesbrough High School and Armstrong College, Newcastle, where he graduated in 1935 with 1st Class Honours in Chemistry. He was subsequently awarded the degree of Ph.D. for research into the chemical properties of graphite. He has been on the staff of the Royal College of Science and Technology (formerly the Royal Technical College) since 1938, and he was appointed Senior Lecturer in 1956. Dr. Carter is a member of the Physical Chemistry of Steelmaking Committee of B.I.S.R.A.

The Rev. T. G. Macfarlane, B.SC., B.D., PH.D., A.R.T.C. Thomas G. Macfarlane was born in 1927 and educated at Allan Glen's School, and the Royal Technical College, Glasgow. He graduated B.Sc., with 1st Class Honours in Metallurgy in 1948, and joined Stewarts and Lloyds Ltd., working for a year in the Department of Research and Technical Development. In 1949 he returned to the Royal Technical College to carry out research on the activity of steelmaking slags under Dr. P. T. Carter and Professor R. Hay. For this he was awarded the degree of Ph.D. in 1953. In the same year he decided to train for the Ministry of the Church of Scotland, and after three years at Trinity College, Glasgow University, he obtained the degree of B.D. in 1956. Dr. Macfarlane was ordained for service as a missionary in the Copperbelt of Northern Rhodesia; after three months' training at St. Colm's Missionary College, he sailed to join the Church of Scotland Mission working in the Copperbelt in January.

[*Mr. Bodsworth, Dr. Carter, and Dr. Macfarlane were authors of papers in the January Journal*].

A. G. Grimshaw—Physics Department, British Iron and Steel Research Association.

Mr. Grimshaw spent four years with the Royal Electrical and Mechanical Engineers before joining the staff of the Army Operational Group, with whom he spent seven years, engaged on experimental work. He obtained a Higher National Certificate in Mechanical Engineering at Kingston Technical College, and in April, 1954, joined the Physics Department of B.I.S.R.A., where he has been working in the Instruments Section.

Dr.-Ing. **C. Herrmann**—Chief Engineer, Demag Aktiengesellschaft, Duisburg, West Germany.

Curt Herrmann was born in 1917 in Brünn, where he studied engineering and graduated at the Technische Hochschule. After five years as New Works Engineer and Shop Manager at the Poldi iron and steelworks at Kladno, he was subsequently employed for a number of years as a consulting engineer in Jugoslavia. In 1951 he joined Demag A.G., and is currently engaged in planning and design work on steelplants.

J. W. Midgley, M.SC., D.I.C.—English Electric Co., Ltd., Mechanical Engineering Laboratories, Whetstone, Leicester.

Mr. Midgley was from 1941 to 1943 with Imperial Chemical Industries Ltd., Metals Division, Birmingham, and was then seconded to the Department of Atomic Energy for four years' research. He then entered Imperial College of Science and Technology, and graduated in physics in 1950. For the next six years he carried out research in the Applied Physical Chemistry Laboratory on lubrication and wear; during that period he held a Wakefield Scholarship and later a D.S.I.R. contract. He is now in charge of solid lubrication and wear research with the English Electric Co., Ltd.

IRON AND STEEL ENGINEERS GROUP

A Meeting of Junior Engineers will be held at Chester and Manchester from Monday to Thursday, 11th–14th March, 1957. The Meeting will include visits to the works of John Summers and Sons Ltd. at Shotton and Metropolitan-Vickers Electrical Co., Ltd., at Trafford Park, Manchester. A lecture on "Engineering Problems in Nuclear Power Stations," by S. A. Ghalib, of A.E.I.–John Thompson Nuclear Energy Co., Ltd., will be given on the Thursday morning, followed by a film of the Calder Hall power station.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Staff Changes

Mr. **J. Savage,** B.SC., F.INST.P., has resigned as Head of the Physics Department of the British Iron and Steel Research Association on appointment as a Director of the Continuous Casting Company Ltd., of Weybridge, Surrey.

Mr. Savage received his technical education at the University of Nottingham, and was awarded the degree of B.Sc. of London University with 1st Class Honours in Physics and Mathematics in 1936. He then joined the Ship Carbon Company of Great Britain Ltd., as a research physicist, remaining with the Company until 1944 when he left to take charge of spectrographic work at the Royal Aircraft Establishment at Farnborough. He joined B.I.S.R.A. in 1947 as Head of the General Physics section; in the following year he became Deputy Head of the Physics Department, and in 1953 he

succeeded Professor M. W. Thring as Head of the Department. He has been primarily responsible for the Association's research and commercial development of continuous casting. He was elected a Fellow of the Institute of Physics in 1952.

Responsibility for the direction of the Physics Department will be assumed, until further notice, by the Deputy Director of B.I.S.R.A., Mr. W. C. F. Hessenberg, M.A. (CANTAB.), F.I.M.

Mr. **L. W. Stevens-Wilson** has been appointed Development Officer to the British Iron and Steel Research Association in succession to Dr. T. E. Dancy, who resigned recently to take up an appointment in the United States with the Technical Services Division of Jones and Laughlin Steel Corporation, Pittsburgh.

Mr. Stevens-Wilson, who is a Fellow of the Physical Society and of the Institute of Directors, a Companion of the Royal Aero Society, and a Member of the Institute of British Engineers, has had a wide experience of the commercial exploitation of new industrial developments, especially in the fields of heavy engineering and chemical processing. After being in charge of the Patents Department of Powell Duffryn Ltd., he served for some years on the staff of the National Research Development Corporation. He relinquished this position some four years ago to form his own organization, S.W. Developments Ltd., specialists in industrial property and patent development and consultants on patent and trade mark affairs. Mr. Stevens-Wilson will continue his association with that firm in the capacity of consultant.

10th Chemists' Conference

One hundred and eighty representatives from firms and research organizations within and connected with the iron and steel industry attended the 10th Chemists' Conference, which was held at Harrogate on 3rd–4th October, 1956. The Chair was taken by Dr. E. Gregory. The first session related to various aspects of sampling and the second session to analytical methods and related safety precautions. As in previous years, the final session dealt with a topic linking the chemists and steelmakers when a lecture on corrosion was delivered by Dr. U. R. Evans. This gave rise to a detailed and interesting discussion. The speakers and their subjects were: Mr. W. T. Elwell (Imperial Chemical Industries Ltd., Metals Division) "An Introductory Talk on the Technique of Sampling," illustrated by an I.C.I. film; Dr. G. V. James, M.B.E. (Rudd Thompson and Partners) "Sampling with Special Reference to Iron Ore"; Mr. J. H. Oldfield (Admiralty Materials Laboratory) "Sampling Problems in Spectrographic Analysis"; Dr. W. Sachs (London and Scandinavian Metallurgical Co.) "Sampling of Ferro-Alloys"; Mr. G. W. C. Milner (United Kingdom Atomic Energy Authority) "Some Analytical Applications of Ethylenediaminetetra-acetic Acid"; Mr. W. R. Nall (Bragg Laboratory, Naval Ordnance Inspection Dept.) "A Non-Destructive Micro-Chemical Method for Sorting Steels"; Dr. L. J. Burrage (Imperial Chemical Industries Ltd., General Chemical Division) "Safety in the Chemical Laboratory"; Dr. U. R. Evans (University of Cambridge) "Quantitative Research on Metallic Corrosion."

INSTITUTE OF METALS

Members of The Iron and Steel Institute have been invited by The Institute of Metals to take part in the latter Institute's Joint Spring Meeting with the Associazone Italiana di Metallurgia, the Association Suisse pour l'Essai des Matériaux, and the Société Suisse des Constructeurs de Machines. The Meeting will be held in London from 29th April to 4th May, and in Birmingham and Sheffield from 5th to 7th May. Full details will be published in the March issue of the *Journal*.

INSTITUTION OF METALLURGISTS

The Institution of Metallurgists held its annual Refresher Course at Llandudno from October 19th to 21st, 1956, when over 250 Members attended. The general theme of the course was the effect of temperature on metals and four excellent papers were presented.

The first Session was devoted to two papers. The first was by Dr. N. P. Allen (N.P.L.) on "The Engineering Properties of Metals at High Temperatures," in which he gave a most valuable resumé of the basic factors of creep, scaling, fatigue, and other properties as affected by temperature. This was followed by a paper by Mr. W. E. Bardgett (United Steel Cos., Ltd.) on "High Temperature Steels," in which the author drew on the extensive researches carried out in his own laboratories and elsewhere, and imparted a great deal of valuable information on the steps taken by the metallurgist to understand the phenomena involved and then to improve the products of the industry.

The second Session of the course was devoted to two papers on the non-ferrous metals, the first by Dr. L. B. Pfeil (Mond Nickel Co., Ltd.), who dealt with developments in the heavy non-ferrous metal field, in his paper "High Temperature Non-Ferrous Materials." The second speaker was Mr. George Meikle (Royal Aircraft Establishment, Metallurgical Department), who dealt with the light metals in a paper on "Behaviour of Certain Metals at Temperatures up to 450° C."

After each paper there was a good discussion and the four papers will now be published by the Institution.

In addition to the Technical Sessions, a visit was paid to the works of Aluminium Corporation Ltd. at Dolgarrog, where the production of aluminium sheet and strip, the blanking of circles, and the production of special finishes was seen. On Saturday evening there was a film show which included the colour film "The Kitimat Story."

NEWS OF SCIENCE AND INDUSTRY

New Metallurgical Society

At a meeting held at the University of Buenos Aires on 20th December, the Sociedad Argentina de Metales was brought into being. This new society, whose objects are to promote the knowledge of metallurgy, to coordinate research and teaching, and to influence the code of professional conduct of its members, has its offices at Diagonal Roque Saenz Peña 555–8th Floor, Buenos Aires, Argentina; the President is Antonio E. Sturla and the Secretary Carlos E. Fernández Molina. Professor Héctor F. Antelo, a Member of The Iron and Steel Institute, is Pro-Secretary.

Tower-testing Station

A tower-testing station opened recently by Stewarts and Lloyds Ltd. at Wirksworth, Derbyshire, has now been in operation for about two months. It is the only station of its kind in the U.K. and obviates the necessity of erecting two towers taller than the one to be tested.

The station is installed in a disused quarry some 150 ft deep enclosed by four vertical cliff walls. This enables towers of up to 200 ft to be tested.

Tests may be carried out on masts, pylons, crane jibs, and similar structures. Ropes are attached to various parts of the structure and loads applied by means of winches. In this way, the effects of wind and cable failure may be simulated and measured.

British Steelworks for India

Under the terms of a contract signed in Delhi on October 30th, 1956, the Indian Steelworks Construction

Co., Ltd. (ISCON), is to construct and equip for the Government of India a complete iron and steelworks at Durgapur in West Bengal. ISCON is a consortium of 13 British companies covering construction, engineering, and steelworks equipment; its offices are at Abford House, 15 Wilton Road, London, S.W.1.

The Durgapur works, when finished, will make a major contribution to Indian steelmaking capacity, which during the second five-year plan is expected to reach five million tons a year. The plant is to have a rated capacity of 1,250,000 tons of ingots and 360,000 tons of pig iron. The output will consist of forging blooms and billets, billets for re-rolling, merchant bar and sections, sleepers, and railway wheels, tyres, and axles.

The construction programme provides for the completion of the entire works by August, 1961, but the first and second blast-furnaces, with adequate coke-oven capacity and ancillary services, will be in operation in November, 1959, and May, 1960, respectively.

Operational Research and Cybernetics at United Steels

With the aim of advancing the latest managerial techniques of control, The United Steel Companies, Ltd., are establishing a new central department of operational research and cybernetics. Based in Sheffield, the department will serve all the branches of United Steels with advice and recommendations on operational research problems, and will provide the personnel to carry out its proposals. Because the whole concept of operational research is itself relatively new, it will also conduct its own research projects and initiate training schemes for those joining its staff.

Initially, the department will have a staff of about 25 research workers, drawn from every branch of scientific endeavour. They will include biologists, physicists, psychologists, engineers, economists, mathematicians, and logicians. Recruitment of additional specialists is proceeding.

Mr. Stafford Beer, formerly production controller at Samuel Fox and Co., Ltd., has been appointed head of the new department. He will work under the general direction of Mr. S. R. Howes, a director of United Steel who, as general manager of Samuel Fox up to June, 1956, was responsible for introducing operational research methods at that works, where they have been applied to production control. This work has been proceeding for seven years and, by the end of 1957, will embrace the whole plant.

It is believed that the new department will be the first in the country to make a formal study of cybernetics —the science of communication and control in the animal and the machine, which seeks to study the analogy between their structure and function. The ultimate objective of this study is to reproduce, by means of mechanical and electronic analogues, the thinking, learning, and discriminating aptitudes of the human brain. A number of experimental analogues have already been constructed, though some considerable period is likely to elapse before full managerial use can be made of this science.

Reference Photographs for Magnetic Particle Indications

Discontinuities in iron and steel castings detectable by the dry powder magnetic particle method may now be classified by comparison with reference photographs recently published by the American Society for Testing Materials at $2·50 as " Tentative Reference Photographs for Magnetic Particle Indications on Ferrous Castings " (E 125–56T). The photographs, showing indications observed on actual castings, have been reproduced through the courtesy of the Steel Founders' Society of America from photographs obtained from its member companies.

Variety Control

The need for ' variety control ' of industrial products was stressed by Professor Harold W. Martin at a recent press conference in London given by the British Productivity Council. The principles of simplification, standardization, and specialization of main basic components did not necessarily mean a standardized end-product, and on the statistical evidence produced by Professor Martin they led to lower costs and higher earnings through improved industrial and commercial productivity.

Continuous Medium-strip Mill at Steel, Peech and Tozer

The new Brinsworth continuous medium-strip mill of Steel, Peech and Tozer, Rotherham, is nearing completion. The motor house, main mill bay, and slab storage bay have been erected, and the coil storage and despatch bays should be ready early this month. The equipment is being rapidly installed, and the target date of March, 1957, for completion should be achieved. During the initial production period, the mill will roll 3000 tons of hot strip a week up to 16 in. wide, thus meeting a need not fulfilled by existing narrow and wide strip mills.

Diesel Locos for British Steelworks

The Hunslet Engine Co., Ltd., of Leeds, have just received an order for eleven more of their heavy-duty steel-works locomotives from the Consett Iron Co., Ltd., at a total value of nearly £150,000. The first diesel order received from this company was just over 10 years ago for a Hunslet 204 h.p. six-wheel locomotive. When this latest order is complete, Consett will have 23 Hunslet diesel shunters in service, comprising nineteen 204-h.p. and four 300-h.p. units—one of the largest diesel fleets at any steelworks in this country.

Corrigendum

In the Discussion on the Acid Bessemer Process (*Journal*, 1956, vol. 184, December, pp. 438–443), the " Authors' Written Reply " on p. 442 was wrongly attributed to Messrs. Wattleworth and Cawley; it was in fact written by Monsieur P. J. Leroy, of IRSID.

Changes of Address and Title

The BETHLEHEM STEEL EXPORT CORPORATION is now known as the BETHLEHEM STEEL EXPORT COMPANY; the European representative remains Mr. Kenneth E. Brown, Brettenham House, Lancaster Place, Strand, London W.C. 2.

The B.S.A. GROUP RESEARCH CENTRE is now at Mackadown Lane, Kitts Green, Birmingham 33 (telephone Stechford 3657–8–9).

The BRITISH STEEL CASTINGS RESEARCH ASSOCIATION has moved to East Bank Road, Sheffield 2 (telephone Sheffield 28647).

The COPPER DEVELOPMENT ASSOCIATION is now at 55 South Audley Street, London W.1 (telephone GROsvenor 8811).

The address of JOS. H. HARRISON AND SON, Consulting Engineers, is now 70 Roman Road, Linthorpe, Middlesbrough.

The London office of the LOEWY ENGINEERING COMPANY LTD. is now 1 Albemarle Street, London, W.1 (telephone HYDe Park 9959).

The address of BABCOCK AND WILCOX LTD. is now Babcock House, 209 Euston Road, London, N.W.1 (telephone EUSton 4321).

The SOCIETY FOR ANALYTICAL CHEMISTRY is now at 14 Belgrave Square, London, S.W.1 (telephone BELgravia 3258).

Industrial Publications Received

Brochure on ' Endewrance ' hard facing welding rods—Dewrance and Co., Ltd., Great Dover Street, London, S.E. 1.

' *Objectif*,' official information bulletin of the Brussels Universal and International Exhibition, 1958: No. 20, November, 1956.

Illustrated technical booklet on self-cleaning air filters—The Visco Engineering Co., Ltd., Stafford Road, Croydon.

Brochures on oil burner controls and Sigma weather-sensitive controllers—Stonebridge Electrical Co., Ltd.

Illustrated catalogue of automatic power plant and control switch gear—Austinlite Ltd., Crawley, Sussex.

DIARY

4th Feb.—Cleveland Institution of Engineers—" Road versus Rail," by S. C. Pearson—Cleveland Scientific and Technical Institution, 6.30 p.m.

4th Feb.—Institute of British Foundrymen (Sheffield and District Branch)—" Some Aspects of the CO_2 Process," by I. Reese and D. H. Snelson—Sheffield College of Commerce and Technology, Pond Street, Sheffield 1, 7 p.m.

4th Feb.—Institute of Welding (Sheffield and District Branch)—" Metal Spraying," by R. Wallwork—Grand Hotel, Sheffield, 7.15 p.m.

5th Feb.—Sheffield Metallurgical Association—" Spectrography," by M. Z. de Lippa—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield 3, 7 p.m.

7th Feb.—Institute of Metals (London Local Section)—" Beryllium," by B. Kjellgren—17 Belgrave Square, London S.W.1, 6.30 p.m.

7th Feb.—Leeds Metallurgical Society—" Fuel Ash Corrosion Problems," by Professor A. Preece—Large Chemistry Lecture Theatre, The University, Leeds, 7.15 p.m.

8th–11th Feb.—National Metallurgical Laboratory of India—Symposium on Mineral Beneficiation and Extractive Metallurgical Techniques—United Club Auditorium, Jamshedpur.

8th Feb.—North East Coast Institution of Engineers and Shipbuilders—" Ceramic Materials for High-temperature Gas Turbines," by T. H. Blakeley—Mining Institute, Newcastle upon Tyne, 6.15 p.m.

11th Feb.—Institution of Production Engineers (Sheffield Section)—" Continuous Casting," by I. M. D. Halliday—Grand Hotel, Sheffield, 6.30 p.m.

11th Feb.—Lincolnshire Iron and Steel Institute—Young Members' Papers—North Lindsey Technical College, Scunthorpe, 7.30 p.m.

12th Feb.—Institute of Metals (South Wales Local Section)—" Neutron Irradiation Effects," by Professor J. G. Ball—University College, Department of Metallurgy, Singleton Park, Swansea, 6.45 p.m.

12th Feb.—Institution of Engineering Inspection—" Investment Casting by the Lost Wax Process," by W. N. Jones—Grand Hotel, Broad Street, Bristol, 7.30 p.m.

12th Feb.—Sheffield Metallurgical Association—" Radioactive Isotopes in Industrial Research," by Dr. D. H. Houseman—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield 3, 7 p.m.

13th Feb.—Institution of Engineering Inspection—" Sampling Systems for Inspection and Quality Control," by B. R. Byrne—Royal Society of Arts, John Adam Street, London, W.C. 2, 6.45 p.m.

13th Feb.—Manchester Metallurgical Society—" Titanium," by Dr. J. W. Rodgers—Central Library, Manchester, 6.30 p.m.

14th Feb.—Institution of Mechanical Engineers (Yorkshire Branch)—" Fatigue under Triaxial Stress: Development of a Testing Machine," by Professor J. L. M. Morrison—The University, Leeds, 6.30 p.m.

14th Feb.—Liverpool Metallurgical Society—" Work Hardening and Dislocation Theory," by Dr. A. H. Cottrell—9 The Temple, Dale Street, Liverpool, 7 p.m.

15th Feb.—West of Scotland and Steel Institute—" Fuel, Steam and Power Balance in Integrated Steel Works," by J. A. C. Cowan and J. Roberts—39 Elmbank Crescent, Glasgow, 6.45 p.m.

16th Feb.—Swansea and District Metallurgical Society—" Modern Developments in Metallurgy," by Dr. D. E. Davies—Central Library, Swansea, 6.30 p.m.

18th Feb.—Sheffield Society of Engineers and Metallurgists—" Radiation Damage to Metals," by W. M. Lomer—Engineering Lecture Theatre, St. George's Square, Sheffield, 7.30 p.m.

19th Feb.—North East Metallurgical Society—" Metallurgical Principles of Light Alloy Foundry Practice," by Dr. W. A. Baker—Cleveland Scientific and Technical Institution, 7.15 p.m.

19th Feb.—Sheffield Metallurgical Association—" Brittle Fracture in Ductile Material," by Dr. S. A. Main—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield 3, 7 p.m.

20th Feb.—Institute of Welding—" Metallurgical Aspects of Welding," by R. Welsh—Cleveland Scientific and Technical Institution, 7.30 p.m.

20th Feb.—Institution of Engineering Inspection—" Inspection of Gear Tooth Elements," by L. A. Turner—Birmingham Exchange and Engineering Centre, 7.30 p.m.

20th Feb.—Institution of Mechanical Engineers (Yorkshire Branch)—" The Fatigue Testing of Aircraft Components," by Dr. R. B. Heywood—Royal Station Hotel, Hull, 7.30 p.m.

20th Feb.—Newport Metallurgical Society—Industrial Films—Whitehead Iron and Steel Institute, Newport, 7 p.m.

20th Feb.—Society of Chemical Industry (Corrosion Group)—" Theory and Practice in Potential Measurements for Cathodic Protection," by P. W. Heselgrave—14 Belgrave Square, London, W.1, 6.30 p.m.

21st Feb.—Ebbw Vale Metallurgical Society (Joint Meeting with The Iron and Steel Institute, Engineers Group)—" The Economics and Development of Continuous Casting," by J. Savage—Richard Thomas and Baldwins Ltd. Lecture Room, 7.15 p.m.

21st Feb.—Staffordshire Iron and Steel Institute—" The Ferrous Die Casting Process," by C. A. Payne—Star and Garter Royal Hotel, Wolverhampton, 7.30 p.m.

26th Feb.—Sheffield Metallurgical Association—" Some Metallurgical Aspects of Creep-resisting Steels," by D. J. Murray—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield 3, 7 p.m.

27th Feb.—Institute of British Foundrymen (London Branch)—" Methods Engineering with Emphasis on the Flow Process applied to Fettling-shop Control," by F. Gaiger and R. Hancox—Constitutional Club, Northumberland Avenue, London, W.C. 2, 7.30 p.m.

27th Feb.—Institute of Metals—Informal discussion on " Degreasing "—The University, Edgbaston, Birmingham.

27th Feb.—Manchester Metallurgical Society—" Mechanism of Diffusion," by A. D. LeClaire—Central Library, Manchester, 6.30 p.m.

28th Feb.—Institution of Engineering Inspection—" Recent Metallurgical Researches in Manchester University," by Dr. H. J. Axon—Engineers' Club, Albert Square, Manchester.

4th Mar.—Cleveland Institution of Engineers—" The Ups and Downs of Ironmaking," by G. D. Elliot—Cleveland Scientific and Technical Institution, 6.30 p.m.

4th Mar.—East Midlands Metallurgical Society—" Recent Developments in Metallography," by D. McLean—Derby and District College of Art, 7.30 p.m.

4th Mar.—Institute of Welding (Sheffield and District Branch)—" Brittle Fracture," by Dr. D. W. Biggs—Grand Hotel, Sheffield, 7.15 p.m.

5th Mar.—Institute of Metals (Oxford Local Section)—" The Writing of Scientific Papers," by Dr. W. Hume-Rothery—Cadena Cafe, Cornmarket Street, Oxford, 7 p.m.

5th Mar.—Institution of Structural Engineers—" Abbey Steelworks," by W. S. Atkins—Cleveland Scientific and Technical Institution, 6.30 p.m.

5th Mar.—Sheffield Metallurgical Association—" Silicate and Alumino-Silicate Analysis," by H. Bennett—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield 3, 7 p.m.

7th Mar.—Institute of Metals (London Local Section)—" Gas in Light Alloys," by Dr. C. E. Ransley—17 Belgrave Square, London, S.W.1, 6.30 p.m.

7th Mar.—Leeds Metallurgical Society—" The Study of Wear and Lubrication Using Radio-isotopes," by J. B. P. Williamson—Large Chemistry Lecture Theatre, The University, 7.15 p.m.

TRANSLATION SERVICE

(The previous announcement was made in the January, 1957, issue of the *Journal*, p. 117.)

Translations Available

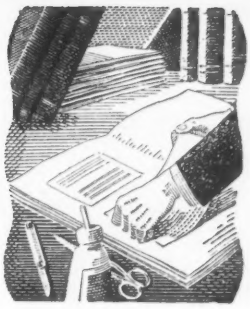
No. 512 (German). H. U. Meyer: " The Influence of Alloying Elements on the Surface Hardenability of Case-Hardening Steels." (*Stahl u. Eisen*, 1956, vol. 76, Jan. 26, pp. 68–77; discussion, pp. 77–78).

No. 513 (German). A. Rose and W. Strassburg: " Kinetics of the Formation of Austenite in Unalloyed and Low-Alloy Hypo-eutectoid Steels." (*Arch. Eisenhüttenwesen*, 1956, vol. 27, Aug., pp. 513–520).

No. 514 (Swedish). G. Wallquist and K. Gedin: " The Magnitude of the Mill Spring in Hot Rolling." (*Jernkontorets Ann.*, 1956, vol. 140, No. 3, pp. 155–187).

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects



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MINERAL RESOURCES

Types of Iron Ore. Prospecting for Iron Ore in Canada, Ancient and Modern. J. M. Harrison. (*Canad. Min. J.*, 1956, **77**, May, 64–65). Lake Superior, Steep Rock, Wabana, Carbonate, Magnetite-skarn, and Taconite types are described.

Oldman River Map-Area, Saskatchewan. D. A. W. Blake. (*Canada Dep. Mines Techn. Surveys, Mem.* 279). The MacRae Lake iron deposit is described.

Mining Miscellany. (*Min. J.*, 1956, **246**, June 8, 711). A brief mention of El Cerro del Mercado, at Durango, Mexico is made. This is a mountain containing 600,000,000 tons of almost pure iron ore.—B. G. B.

New Zealand's Magnetite and Ilmenite Deposits. (*Min. J.*, 1956, **246**, June 1st, 672).

ORES—MINING AND TREATMENT

Agglomeration of Slurries from the Chiatursk Deposits. M. A. Kekelidze and V. V. Perova. (*Izvestiya Akademii Nauk SSSR, O.T.N.*, 1956, No. 3, 111–115). [In Russian]. Sintering of residues settled from slurries obtained during beneficiation of the Chiatursk manganese ores was investigated. Optimum sintering conditions were established.—V. G.

Iron Ore Mine under the Baltic. (*Min. J.*, 1956, **246**, June 8, 705). A brief description of a Finnish iron ore mine which is being developed under the sea from the island of Nyhamn. The ore is of similar quality to that of central Sweden.—B. G. B.

Malaya's "Hill of Metals." (*Australasian Eng.*, 1956, **48**, Mar., 56). An account of the iron mine at Bukit Besi is given and illustrated.

Methods and Operations at the Kaiser Steel Corp. Eagle Mountain Iron Mine Riverside County, Calif. R. R. Trengove. (*U.S. Bur. Mines Inform. Circ.* 7735, 1956, Feb., pp. 25). A detailed account of the mining layout and practice at this open cast mine is presented. 2·5 million tons of ore is required per year for the Fontana plant of the company.—B. G. B.

Nairne Pyrites Plant Officially Opened. (*B.H.P. Rev.*, 1956, **33**, Apr., 10–12). The official opening of the Nairne pyrites plant at Brukunga, South Australia is described, and the development, construction, and capacity of the plant are outlined.—L. D. H.

Uranium Processing. Government Gold Mining Areas. Pyrite Recovery Plant. L. A. Waspe. (*Canad. Min. J.*, 1956, May, 74–76). The plant at the South African Government Areas Mill is described.

Some Notes on the Beneficiation of Iron Ore. T. Szreter. (*Hutnik*, 1955, **22**, (10), 350–358). A brief discussion of different methods of beneficiation with the object of obtaining a combination of high Fe content and a low Fe/SiO_2 ratio. Tabulated results show that best results can only be obtained through a combination of several methods.—W. E. & A. P. M.

Transport in Suspension in Ore Dressing Plants. G. Salzmann. (*Z. Erz. Met.*, 1955, **8**, Special No. B137–B144). Full calculations and data are presented for various sorts of pumps, with viscosity and other tables for magnetite, galena, and ferrosilicon suspensions.

Development of the Inco Iron Ore Recovery Process. (*Canad. Min. Met. Bull.*, 1956, **49**, May, 337–343). Laboratory pilot plant and full scale operations for separation of iron and nickel from pyrrhotite are described with particular reference to the production of a high grade iron concentrate. Roasting, reduction, leaching, separation of ore and pelletizing and firing are described.

Grading Minnesota Iron Ores for the Blast Furnace. M. W. Griswold. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 7–12). The author draws attention to the lack of uniformity of Minnesota ores and describes the methods used by Inland Steel Co. to produce a uniform shipping grade from these heterogeneous ores. He discusses sampling and analysis of the ores, the grades shipped, and the grading and sectioning of the cargo.—G. F.

The New High-Grade Iron Ores and Agglomerates and their Effect on Coke Rates. J. Griffen. (*Amer. Inst. Min. Met. Eng.*, 1956, *Preprint*). A review of raw materials becoming available with a forecast of future conditions, and including data on operation on sinter and on nodulized ores, is presented.

Heat Treatment of Mineral Materials. V. Charrin. (*Chaleur et Ind.*, 1956, **37**, June, 170–176). Drying, baking, calcination, roasting, carbonization, and fusion of various mineral materials are discussed in relation to their uses, viz. removal of combined water and CO_2, flash roasting of ores, treatment of bituminous materials, and smelting.—T. E. D.

More Sinter for the Blast Furnace. (*Steel*, 1956, **138**, May 14, 126–128). Two iron ore sintering machines which are to be built by Koppers Co. Inc. are mentioned. They will have 12 ft wide beds, be 160 and 200 ft long, and have capacities of 6000 and 7000 tons sinter daily.—D. L. C. P.

Sintering Practice at Ford Motor Company. R. L. Cleveland. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 15–23). The author describes the

present sintering facilities at the Ford Motor Co., referring particularly to the use of high-iron concentrates produced from low-grade Humboldt hematite deposits. Production tests show that up to 30% concentrate fines in the machine feed will produce good quality sinter with iron content high enough to compensate for slight reductions in normal tonnages. (See also *Blast Furn. Steel Plant*, 1956, **44**, May, 493–497. C. Hoffman).—G. F.

The Effect of Cooling Rate on Sintered Iron Ore. T. Sloniowski. (*Hutnik*, 1955, **22**, (10), 369–371). The allotropic transformation of $2CaO.SiO_2$ is accompanied by a 10% vol. increase, and self-fluxing sinters containing this compound are liable to disintegrate if water-cooled before the temperature of the sinter has been reduced to 300° C.—W. E. & A. P. M.

Calculation of the Sintering Charge. I. L. Malkin and F. M. Bazanov. (*Stal'*, 1955, (9), 788–790). [In Russian]. Equations are presented for calculating the composition of the sinter mix to give a product of a specified composition, including FeO-content. An accurate and simple method for such calculations is developed and its use is illustrated by application to the production of 100 kg of fluxed sinter of given basicity from a mixture of ores, limestone, flue dust, and coke fines. Assumptions or experimental data are used for the extent of desulphurization, carbon gasification, and manganese oxide reduction. The relation between fuel content in the mix and FeO content in the sinter is obtained from practical data.—S. K.

Grid for Lighting the Sinter Charge in Experimental Sinter Boxes. A. G. Neyasov. (*Stal'*, 1955, (9), 846). [In Russian]. A rigid metal framework with a wire network stretched over it and interspaced with asbestos is soaked in paraffin and placed, lighted, over the top of the sinter charge. The arrangement enables the top of the charge to be observed during ignition.—S. K.

Reaction Zones in the Iron-ore Sintering Process. R. D. Burlingame, G. Bitsianes, and T. L. Joseph. (*Amer. Inst. Min. Met. Eng.*, 1956, *Preprint*). Dissection procedures for immediate and accurate sampling of partially sintered beds have shown the following zones (from top to bottom) to be clearly marked by changes in colour: (1) sinter cake; (2) narrow zone of combustion and sinter formation; (3) zone of calcination and reduction; (4) zone of dehydration; (5) dry zone; (6) wet zone. The chemical composition changes within each zone are discussed, and methods of impregnating and sectioning partially sintered beds are described.—G. F.

Methods for Increasing Production Rate of Flue-dust Sinter. E. C. Rudolphy and E. J. Whittenberger. (*Amer. Inst. Min. Met. Eng.*, 1956, *Preprint*). The authors show that the production rate of flue-dust sinter is increased by means of moisture control and additives such as ore fines, roll scale, return fines, and granulated blast-furnace slag. Problems associated with obtaining and maintaining high permeability and production rates are discussed, and the need for control instrumentation and adequate equipment for handling materials is emphasized.—G. F.

Study of the Productivity of Conventional Dwight-Lloyd Sintering Machine. M. O. Holowaty, H. A. Goldfein, and C. B. Sheets. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 43–75). The authors have investigated the possibilities of increasing the production of existing sinter machines. The factors affecting production rate are discussed in detail, and an experimental programme to study the effect of feed permeability on sintering rate is described. The calculated of air requirements and the determination of the blowing capacity of a sintering fan are next considered, and the effect of fuel size and quantity on production rate and quality of the sinter are discussed. The control of operational variables is dealt with, and it is concluded that proper changes in equipment and practice can substantially increase production rates in conventional installations.—G. F.

Production and Properties of Experimental Pellet-Sinter. F. M. Hamilton and H. F. Ameen. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 82–89). A description is given of a laboratory machine producing " pellet-sinter " agglomerate by a combination of the pelletizing and sintering processes. The method of operation is outlined and the results of physical tests on the product are given. The work indicates that pellet-sinter of satisfactory quality can be produced on a sinter-type strand at an acceptable production rate.—G. F.

The Making of Self-fluxing Sinter and Its Use in the Blast Furnace. C. Danielsson. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 134–149). At the Domnarfvet blast furnace plant, the limestone and manganese ore are added in the sinter plant to produce a self-fluxing sinter. The sinter practice is described, and problems related to sinter quality and plant productivity are discussed. Results of experiments and trials on operating furnaces are also described.—G. F.

Production and Use of Iron Coke: I. Development of Process; II. Production of Iron Coke by Republic Steel Corporation; III. Results Obtained from Use of Iron Coke in the Blast Furnace. C. C. Russell, P. Whitstone, and R. P. Liggett. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 93–119). Part I deals with the Koppers Company's investigation into the possibilities of producing " iron coke " by carbonization of a mixture of iron oxides and coal. The literature is reviewed and descriptions are given of laboratory investigations and small-scale and full-scale oven tests. Parts II and III described subsequent trials at the Republic Steel Corporation on the production and use of iron coke. The coke oven practice and the properties of the product are described, and some of the problems and difficulties encountered are discussed. A summary of the results obtained in two trial periods using iron coke in the blast furnace shows that the material can be used in amounts exceeding 10% of the total coke, if correctly screened and sized.—G. F.

Ore Preparation Plant of the Steel Company of Wales Limited—Design, Operation, and Effect on Blast Furnace Performance. K. C. Sharp and H. R. Tufnail. (*Amer. Inst. Min. Met. Eng.*, 1956, *Preprint*). A detailed description is given of the design and operation of the ore preparation plant at the Margam works of Steel Co. of Wales Ltd. The ore crushing and screening, coke breeze preparation, and sintering units are dealt with separately. The effect of the sinter on blast furnace performance and iron quality is discussed.—G. F.

FUEL—PREPARATION, PROPERTIES, AND USES

High Efficiencies attained by Cold Combustion of Coal. H. W. Hahnemann. (*Z.V.d.I.*, 1956, **98**, Jan. 1, 13–14). This is a brief survey of current developments of fuel cells.

Corrimal Colliery—First Coal Preparation Plant in Australia. B. A. Price. (*G.E.C.J.*, 1956, **23**, July, 152–164). A washing plant is described and illustrated. The coal is largely used in beehive ovens for foundry coke production.

The Use and Properties of Ferrosilicon in Heavy Medium Separation. F. Rodis. (*Z. Erz. Met.*, 1955, **8**, Special No. B145–B150). Preparation and properties of the suspensions, and losses by adhesion are considered in detail.

New Milestone in Coking Industry. (*Gas World*, 1956, **143**, 1172–1173). The contents of the address given by Sir Frederick Scopes at the opening of the Acton Testing Station of the British Coking Industry Association are reported.—T. E. D.

Coal Heating with H.F. Currents. S. G. Aronov and Yu. B. Tyutyunnikov. (*Stal'*, 1955, (9), 771–776). [In Russian]. The use of H.F. heating in coking was studied with coal charges weighing up to 2 kg. The mechanical properties of the material obtained with upper temperatures of 450–460° C were compared with those of the corresponding products obtained by external heating.—S. K.

The Influence of Compression of the Coal Charge on the Properties of Coke. B. Kalinowski, A. Grossman, and B. Kowalski. (*Hutnik*, 1955, **22**, (7/8), 247–252). Coke ovens were charged by free falling coal, and by a pressure method causing a densification of $\sim 35\%$. Compression increases the resulting coke strength by $\sim 12\%$ and abrasion resistance by $\sim 37\%$, while simultaneously raising the burden per chamber.—W. E. & A. P. M.

A Study of Pressure Relationships in Commercial Coke Ovens. D. C. Coleman and P. J. Farley. (*Amer. Inst. Min. Met. Eng.*, 1956, *Preprint*). The authors describe an investigation of the pressure-developing properties of coal and of their effect on commercial carbonization. Data obtained from movable-wall test-oven charges and from gas probe tests in commercial ovens are presented and correlated.—G. F.

Statistical Quality Control in the Coke Plant. R. E. Franks. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 243–263). The author discusses

statistical methods of quality control in the coking plant, involving the recording of data by means of Skewhart control charts. Examples of the use of these charts are given, and the benefits gained from statistical control methods are outlined.—G. F.

Economic Aspects of Coal-chemicals from Coke-oven Gas. R. W. Vollmer and W. E. Simmat. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 279–286). The authors discuss some of the economic benefits that could be derived from the production of additional saleable products from coke-oven gas. Examples of additional product recovery are given and the value of the products is estimated.—G. F.

Consideration and Assessment of Coke Dry Cooling. A. E. Morris. (*Inst. Gas Eng. Publ.* 487, pp. 37).

Coke from Brown Coal. (*Australasian Eng.*, 1956, **48**, Mar., 57). The first successful use of brown coal coke for iron smelting in Victoria is noted.

Metallurgical Fuel from Victorian Brown Coal. H. K. Worner. (*Proc. Australasian Inst. Min. Met.*, 1956, No. 177, March, 49–68). Production of a hard lump char is described, with cupola trials.

The Comparison and Significance of Various Methods of Determining the Mechanical Properties and Reactivity of Coke. A. Grossman. (*Hutnik*, 1955, **22**, (7/8), 240–246). It is considered that the reactivity of coke is controlled by grain-size and porosity, and that the present standard laboratory tests do not allow a proper evaluation of these factors. The mechanical strength tests are also considered insufficient, since they often refer only to a limited range of sieve sizes. Permeability tests are more satisfactory in this respect. Tests should be carried out on a larger scale under conditions more closely approaching industrial practice.—W. E. & A. P. M.

Heavy Fuel-oil Gasification for Metallurgical Furnaces. (*Found. Trade J.*, 1956, **100**, June 7, 415–417). The principle of the oil-gasification process is reviewed and a brief report is given of the experience gained by a British team from visits to two French works. The advantages over normal coal-fired gas producers are summarized and it is concluded that there is considerable scope for oil gasification in high temperature processes such as reheating furnaces and ceramic kilns.—B. C. W.

REFRACTORY MATERIALS

Correlation of Chemical Composition and Physical Properties of Dolomite. E. Zen. (*Amer. J. Sci.*, 1956, **254**, Jan., 51–60). The work described is primarily concerned with the conditions of formation of the rock.

Recent Developments in the Refractories Industry. B. Eichler. (*Refract. J.*, 1956, **32**, Apr., 156–169). Progress in the basic refractories field is contrasted with that in the aluminous and acid field. Specific applications are considered; firebricks and the production of silica brick from flint are particularly dealt with.—D. L. C. P.

Higher Productivity in the Refractories Industry. H. Pattison. (*Refract. J.*, 1956, **32**, Feb., 52–72). The meaning of productivity is discussed and means of measurement and improvement in the refractories industry are considered. Illustrated examples of method and work study are given.

Refractories Research and its Applications in Great Britain. A. L. Roberts. (*Refract. J.*, 1955, **31**, Aug., 444–456). Research work in the following 3 fields is described: the mineralogy of fireclays; high temperature testing of refractories by torsion methods; the transformation of quartz at high temperatures.

Refractories for the Iron and Steel Industry. (*Refract. J.*, 1955, **31**, Sept., 492–500). Work concerning refractories, reported in the 11th Annual Report of B.I.S.R.A. for 1954 is summarized. Subjects include: carbon hearths and under-hearth cooling; condition of blast furnace linings; practical suction pyrometers; ingot moulds and heads; ladle linings; trial roof panels; design of checkers and slag pockets.

Oil Firing as Applied to the Burning of Refractory Goods in Intermittent, Continuous and Tunnel Kilns. A. B. Pritchard. (*Refract. J.*, 1955, **31**, Dec., 638–648). Characteristics and advantages of oil firing are noted, and examples of its application to refractory products are considered.—D. L. C. P.

The Ceramic Industry of the U.S.S.R. A. Kopeikin. (*Clay-craft*, 1956, **29**, Sept., 690–692). A small section on refractories and an illustration of a tunnel kiln for firing them are included.

Factors Affecting Strength of Clays in the Temperature Range 110° to 800° C. W. H. Sutton and F. R. Matson. (*J. Amer. Ceram. Soc.*, 1956, **39**, Jan., 25–30). The effect of heat treatment was shown by transverse strength–temperature curves for three kaolinitic clays, and the results indicated that both dry and fired strengths were considerably affected by aging, firing temperature, and chemical treatment of the kaolin.—D. L. C. P.

Testing Refractoriness. R. Zoja. (*Met. Ital.*, 1956, **48**, Feb., 68–72). [In Italian]. The author describes new refractoriness tests carried out on spherical samples of ternary mixtures of the CaO–MgO–SiO_2 system. The isothermal curves given for various grades of softness show some characteristic features which are discussed. (5 references).—M. D. J. B.

Some Rate Processes in Ceramics. J. H. Cannon and J. White. (*Trans. Brit. Ceram. Soc.*, 1956, **55**, Jan., 82–108). The general principles governing rate processes are stated and the nature of the rate determining mechanism in various processes of importance in ceramics is discussed.—D. L. C. P.

Alteration of Refractory Magnesite Blocks in Cement Kilns by formation of Clinker Deposits. N. Sundius. (*Radex-Rundschau*, 1956, Feb., 10–13). The mechanism of failure is worked out.

Specifications for Coke Oven Refractories. S. Golczewski. (*Hutnik*, 1955, **22**, (11), 393–401). The suitability of constructional materials, cements, lime, bricks and refractories for different parts of the ovens is discussed in the light of Polish Specifications.—W. E. & A. P. M.

The Effects of Dissolved or Adsorbed Inactive Gases on the Reactivity of Oxides. J. A. Hedvall. (*Trans. Brit. Ceram. Soc.*, 1956, **55**, Jan., 1–12). Experiments are described which show the effects of preheating the various modifications of SiO_2, with Al_2O_3 and with Fe_2O_3, in oxygen, air, sulphur dioxide and sulphur trioxide at different temperatures. The dissolved or adsorbed gas affects the surface activity of the solid, and consequently effects mechanical, physical, and chemical surface processes.—D. L. C. P.

The Reaction between Dead-Burned Magnesite, Carbon Dioxide and Water. K. Allgeuer and F. von Kahler. (*Radex Rundschau*, 1955, (**6**), Sept., 563–570). Details, data, and results are reported of investigations of the CO_2 pick-up of moist dead-burned magnesite in relation to CO_2 pressure and water content. X-ray and differential thermal analysis studies show that heating converts the hydrated product to the equivalent of commercial magnesium carbonate. Kinetics of the reactions are discussed.—E. C.

The Mechanism of Bursting Expansion in Chrome-Magnesite Bricks. G. R. Rigby. (*Trans. Brit. Ceram. Soc.*, 1956, **55**, Jan., 22–33). Old and new work is considered in proposing that the mechanism of bursting expansion that occurs when refractory materials containing chrome ore absorb iron oxide has its origin in unequal diffusion that occurs in the solid state.—D. L. C. P.

Kinetics of the Quartz Transformation. R. W. Grimshaw, J. Hargreaves, and A. L. Roberts. (*Trans. Brit. Ceram. Soc.*, 1956, **55**, Jan., 36–55). The transformation of pure quartz was studied and the effect of catalysts determined. Additions which form a liquid phase at the firing temperatures give rapid conversions; CaO is a comparatively vigorous solid catalyst; Al_2O_3 has a pronounced retarding influence.

Use of Fireclay Bricks in Steel Ladles. H. R. Lahr. (*Iron Coal Trades Rev.*, 1956, **172**, Apr. 27, 481–485). The author discusses a number of works trials in which 16 types of ladle brick, with Al_2O_3 contents from 24% to 43%, were compared. The results show that the silica–alumina ratio is less vital than the porosity, the lowest porosity giving the best service. Other factors affecting ladle life are also discussed.—G. F.

Refractory Products for Blast Furnaces. L. Halm. (*Doc. Met.*, 1956, Apr.-May-June, 189–200). A discussion is given of the refractory materials which are used in the hearth, bosch, and shaft of a blast furnace. The fundamental properties required of aluminosilicate and carbon bricks if they are to have a satisfactory life in a blast furnace are considered.

Lining Mixer Bottoms with Rectangular Bricks. (*Radex Rundschau*, 1955, (7), Nov., 632–633). Considerable advantages in simplicity of laying and increased service life are claimed for a new system of lining mixer floors with rectangular blocks. Triangular spaces at the joins between floor and walls are filled with magnesite ramming.—E. C.

Use of Basic Refractories in European Open Hearth Practice. A. H. Sommer. (*J. Met.*, 1956, **8**, Apr., 443–444). The author briefly outlines his impressions of European open-hearth basic refractory practice. He feels that the all-basic roof necessi-

tates a more extended use of basic refractories throughout the entire regenerative system, if maximum furnace life and economy are to be obtained.—G. F.

Use of Forsterite Brick in Regenerator Packing. V. F. Gusev, G. A. Molotkov, and A. L. Turubiner. (*Stal'*, 1955, (9), 838–841). [In Russian]. The use of forsterite brick in regenerators for O.H. furnaces with chrome–magnesite roofs working at temperatures up to 1750° C was investigated. Samples of the brick were periodically extracted during furnace maintenance and the behaviour of the brick in single and double pass type regenerators compared. Different packing arrangements are considered and the one giving best heat exchange and resistance to dust action is described. In general forsterite brick in air regenerators enables both life and operating temperatures to be increased, with corresponding improvements in furnace operation.—S. K.

Checker-brick Trials (Superduty and High-alumina). R. F. Urban. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 103–108). Special bricks and normal checker brick have been compared in works trials at Bethlehem Steel Co.'s Sparrows Point works. Superduty and "stiff-mud" types of brick gave no better service than the normal brick, but 55–60% alumina bricks gave better service and are undergoing further tests. 60–70% alumina bricks are also being tested.—G. F.

Special Refractories for Checker Brick. C. C. Benton. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 109–112). Trials of basic checker bricks have been carried out on 150-ton oil-fired O.H. furnaces at Algoma Steel Corporation. The results show that basic bricks can be used economically, either as full checkers or as top courses on normal checker bricks, giving a trend towards higher production rates and lower fuel rates. After 700 heats, no dust adherence or slagging was found, and the flues remained open without blowing for the entire campaign.—G. F.

Refractories for Arc Furnaces for Ferro-alloy Production. H. Bederlunger. (*Radex-Rundschau*, 1955, Dec., 650–658). Furnace linings for the production of ferrosilicon, ferromanganese, ferrochrome, ferro-tungsten, and ferro-vanadium are discussed and trials with carbon and magnesite blocks described in the case of ferro-tungsten, also blocks of 20, 40, and 60% magnesite with carbon.

Six Effective and Efficient Methods of Applying Mineral Wool Block on Flat Surfaces. (*Indust Heating*, 1956, **23**, Feb., 359–370, 378). Six methods of fixing mineral wool blocks for the insulation of gas and air ducts are described.—A. D. H.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

The Furnace at Izurdiaga for Making Pig Iron from Ores and Industrial Residues. J. A. Morales Belda and J. A. Berazaluce Altadill. (*Inst. Hierro Acero*, 1956, **9**, Jan.-Mar., 241–249). [In Spanish]. A description is given of the pilot furnace, installed in 1954 (Spanish Patent 216,640) for the production of pig and cast iron from low grade raw materials at low cost. It is operated with a single-valve controlled regenerator system with up and down circulation through the furnace. An output of 5·5 t per day is obtained with a 1 m dia. furnace using 1000 kg coal/ton, with 12 m^3 air/kilogram coal and a blast of 60 $m^3/m^2/min$. Rectangular sections are preferred for larger furnaces. A system using horizontal, opposing tuyeres is also proposed.—P. S.

Replace Furnace Faster by Off-Site Construction. (*Iron Age*, 1956, **177**, May 31, 72–73). The siting of the prefabricated shell of a 25 ft hearth blast furnace at Granite City Steel Co. is described. The shell, from mantle to bleeder stacks, weighed 635 tons, and was moved 84 ft and lowered into position on the columns in 13 hours. The time taken from blowing out the previous smaller furnace to blowing in the new one on the same site, was about 5 months, and the time saved by prefabrication, 4 to 6 weeks.—D. L. C. P.

Blast Furnace in Moth Balls. (*Steel*, 1956, **138**, Mar. 26, 134–137). The sealing up of the bosh of a blast furnace which was kept banked for 55 days is described. Several layers of a low viscosity vinyl plastic were sprayed on to give an air-tight coating, which was easily stripped off when required.

Blast Furnace Shell Moved 84 Feet to Foundation of Replaced Furnace. (*Blast Furn. Steel Plant*, 1956, **44**, July, 755–756). A short account of the moving of a 635-ton blast furnace shell to a previously prepared foundation is given.—B. G. B.

Blast-Furnace Gas Conduits. L. Lepage and N. Dubois. (*P.A.C.T.*, 1956, **10**, June, 204–209). With a view to preventing carbon monoxide poisoning accidents and explosions, this paper reiterates the essential rules to be observed in the installation of blast-furnace gas conduits and auxiliary equipment. Precautions to be taken by personnel are also mentioned. Finally, a control programme for conduits and equipment is proposed.—T. E. D.

The Demag-Humboldt Low-Shaft Furnace Process. H. Reinfeld. (*Radex Rundschau*, 1955, (6), Sept., 525–543). An historical survey of the low-temperature carbonization process and its application to iron ore smelting in low-shaft furnaces is followed by a detailed account of the development and principles of the Demag-Humbold system. Full scale trials are reviewed and materials balances and product studies are discussed in assessing the performance of this type of low-shaft-furnace.—E. C.

The Development of the Low Shaft Furnace Process in the German Democratic Republic. K. Sauberlich. (*Neue Hütte*, 1956, **1**, Feb., 193–201). Fundamental studies on an experimental furnace having shown that the low shaft furnace was feasible, experiments were undertaken on a pilot plant scale, after which the CALBE furnace was built. Since then efficiency has been increased, and lignite high-temperature coke is now used exclusively.—L. J. L.

Building Characteristics of Low Shaft Furnaces in the German Democratic Republic. R. Baake. (*Neue Hütte*, 1956, **1**, Feb., 202–215). The effect of the height of the charge column, the furnace load, and coke consumption on the design of low shaft furnaces is discussed, comparisons being made with blast furnaces. The choice of circular or rectangular furnace cross-section is discussed with reference to blower capacity and blast penetration. The importance of burden processing, correct sizing of burden constituents, the relation between lump size, heat transfer, and shaft height, sieving of fines, and briquetting are also discussed.

A New Experimental Technique for Studying the Blast-furnace Process. S. Klemantaski. (*J. Iron Steel Inst.*, 1957, **185**, Feb., 237–238). [This issue].

Rate of Sulphur Transfer between Blast-furnace Type Metal and Slag. S. Ramachandran, T. B. King, and N. J. Grant. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 338–349). A brief review of laboratory work on desulphurization is presented and the results obtained are compared with practice. A description is then given of a new apparatus combining conventional sampling techniques with automatic measurement of CO evolution as a measure of desulphurization rate during the reaction. Some preliminary results are presented.—G. F.

Blast Furnace Stove Cleaning. L. R. Robinson. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 155–158). The author discusses the effect of hot blast on blast furnace operation, coke rate, and production, and emphasizes the need for maintaining stove efficiency. The "rotary rod" method of cleaning stove checker work is described, and the cost of the method is compared with the savings effected.—G. F.

Maximum Cleaning for the Blast Furnace Stove. A. D. Nesbitt, C. Komp, and R. F. Scholl. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 159–171). The authors describe a chemical-hydraulic method for cleaning blast furnace stoves, combining chemical treatment with high-pressure hydraulic jet lancing of the checker flues. Details are given of the application of the method to a ball insert checker stove and to a McKee cluster stove.—G. F.

Rate of Reduction of Iron Oxide from a Blast-furnace Type Slag by Liquid Iron in Carbon Crucibles. W. O. Philbrook and L. D. Kirkbride. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 326–335). The authors have measured the reaction rate for the reduction of FeO from lime–silica–alumina slags over carbon-saturated iron, and found it to be proportional to about the second power of the analysed iron content of the slag. The experimental apparatus and procedure are described, and the relation of the results to sulphur transfer and to blast furnace reactions are discussed.—G. F.

Kinetics of Reduction of Iron Oxides by Gaseous Reducing Agents at Low Temperatures. A. G. Moskvicheva and G. I. Chufarov. (*Doklady Akad. Nauk. S.S.S.R.*, 1955, **105**, (3), 510–513). Siderite, haematite, and pure synthetic Fe_2O_3 and Fe_3O_4 in powder form were reduced in carbon monoxide

on hydrogen in a closed apparatus at controlled temperature, gaseous products being frozen out from the circulating gas. The temperature range was 200–300° C and the pressures 240–260 mm and 0·1–0·01 mm. A mechanism is proposed depending upon change to a spinel structure with inward diffusion of iron atoms.

TREATMENT AND USE OF SLAGS

A Survey of Methods for Slag Control. W. E. Clarke. (*Brit. C.I. Res. Assoc. J. Res. Dev.*, 1956, **6**, Apr., 195–212). A survey is made of published methods which have been suggested as rapid alternatives for chemical analysis in the estimation of the important constituents in slags. The background of knowledge of the desirable slag composition for cupola operation is not considered sufficient to develop and apply the rapid control methods of the type reviewed, such as are in use in the steel making industry. (53 references).

The Fluxing of Iron Ore Gangue by Dolomitic Limestones. P. D. S. St. Pierre. (*Canad. Min. Met. Bull.*, 1956, **49**, May, 360–367). The requirements for an iron-making slag are outlined. The laboratory technique for study of the CaO–MgO–Al_2O_3–SiO_2 system is described and the liquidus temperatures of numerous compositions are given.—T. E. D.

Composition of Steelmaking Slags: A Suggested Fresh Approach. D. J. O. Brandt. (*Iron Coal Trades Rev.*, 1956, **173**, July 20, 147–150). Recent methods of studying slag control problems in steelmaking have been concentrated largely on the concept of activity. The author discusses the problem from the practical standpoint, suggesting a possible re-orientation of effort based on a more detailed knowledge of the shape and position of the liquidus of phase diagrams corresponding reasonably closely with the analyses of steelmaking slags.—G. F.

PRODUCTION OF STEEL

Advances in Steel Technology in 1955. (*United Nations Report. E/ECE/238; E/ECE/STEEL/102.* 1956, Feb., pp. 288). **Foreword.** H. Malcor. (1–5). **Economic Importance and Present Position of Ferro-coke Production and Smelting.** H. Barking and C. Eymann. (6–12). After an account of experiments, manufacture is described and blast-furnace use and advantages outlined. **The Coking of Lorraine Coals.** L. Laurent. (13–25). After a general introduction, the Carling and Marienau plants are described. The selective crushing (Sovaco) process is then outlined, followed by statistics and future prospects. **Production of Brown Coal High-Temperature Coke.** E. Rammler. (26–43). Processes are outlined with flow-sheets, and properties and compositions are given. **Sintering of Fines Produced by Crushing and Screening Lorraine and Luxembourg Iron Ores.** J. Paquet. (44–48). Equipment and the physical and chemical properties of the products of Dwight Lloyd and Rotary Furnace processes are described. **The Application of the Krupp-Renn Process in Czechoslovakia.** (49–53). Advantages and disadvantages are set out and the trend of research is mentioned. **Pelletization of Haematite Ores from Elba.** F. Savioli and C. Mellere. (54–58 + ii). Laboratory trials and the development of plant up to the planning of the full-scale installation are described. **The Use of Fluxed Sinter in Blast-Furnaces.** U.S.S.R. Delegation. (59–65). Works trials are outlined and the results tabulated. **Utilization of Red Mud in Hungary.** L. Visnyovszky and (Mrs.) J. Holló. (66–70). Alumina, sodium salts, and titanium oxide recovery is referred to, and the use of red mud as a binder for ore briquettes outlined. Blast-furnace tests are not available. **The Use of Wet Blast of Constant Humidity in Blast Furnaces.** U.S.S.R. Delegation. (71–73). Humidification is described and shown to be advantageous. **The Use of High Top Pressure in Blast-Furnaces.** U.S.S.R. Delegation. (74–77). The extent of the oxidizing zone changes very little in a radial direction, the central part provides normal conditions for reduction and heat-exchange, the pressure drop is reduced permitting intensification of operation with even sinkage of burden, the gas is more fully utilized, and iron of more constant composition is produced. **High Top Pressure.** R. Towndrow and W. Banks. (78–84 + ii). Theory, furnace modification, and British experience is discussed. **A New Process for Desulphurizing Pig Iron.** M. Allard. (85–87). The process of injecting powdered lime in an inert or reducing gas is described. **Reduction of Iron Ores by Natural Gas.** A. Scortecci. (88–98 + ii). Italian practice is outlined with an account of current research and possible methods. Plant for production of sponge iron using methane is now planned. **The Use of Natural Gas in the Reduction of Iron Ores.** H. Galluser. (99–102 + i). Swiss work is described. **The Use of Brown Coal High-Temperature Coke in Low-shaft Blast-Furnaces.** G. Brückner. (103–108). Tests at the Maxhütte (Eastern Germany) works with Iauchhammer coke are described. **Basic Bessemer Conversion Processes.** P. Coheur. (109–128 + xii). A comprehensive account with many diagrams. (62 references). **New Converter Profiles.** P. Leroy. (129–134 + iii). **Precipitation of Brown Fumes.** G. Husson. (135–140 + ii). Dust precipitation plant is described. **De-Dusting of Brown Fumes from Converters.** K. Guthman. (141–148 + iv). Characteristics and composition of the fumes are given and plant is discussed. **Continuous Measurement of Temperature in Basic Converters.** G. Husson. (149–152). The IRSID two-colour pyrometer is discussed and the effect of temperature on nitrogen content of basic steel determined with its use is given. **Control of Thomas Process by Temperature and Spectrum Measurement.** F. Wever, W. Koch, H. Knüppel, K. Meyer, and G. Wiethoff. (153–157 + iii). **Observations on the Technical Development of the New Oxygen Steelmaking Process (LD. Process) in Austria and Other Countries.** B. Matuschka. (159–167 + i). **The Steel Industry and International Flame Research.** M. Rivière. (168–172). A review with 15 references. **Gasification of Heavy Oils: OCCR Process.** H. Guillon. (173–184). Heat-treatment and re-heating furnaces have been run from the producer. **The Use of Chrome-Magnesite Bricks for the Roofs of Open-Hearth Furnaces.** U.S.S.R. Delegation. (185–188 + iii). Roof construction is illustrated and shown in detailed diagrams and experience with the new construction is reviewed. **The Production of Stabilized Dolomite and of Refractory Bricks Therefrom.** Polish Delegation. (189–208 + iv). **Uses of the Lubatti Furnace.** E. Lubatti. (209–212). **The Steckel Rolling Mill.** J. Hamus. (213–214). **The Modern Combined Bar and Wire-Rod Rolling Mill.** E. Norlindh. (215–227 + vi). Design and operation is discussed in detail. **The Automation of Rolling Mill Production in the U.S.S.R.** U.S.S.R. Delegation. (229–232). **Automatic Gauge-Control During Rolling.** P. Blain. (233–246 + xiv). Principles, apparatus and operation are reviewed. **Extrusion of Steel by the Ugine-Sejournet Process.** J. Séjournet. (247–260). Glass lubrication is used. **The Manufacture of Electrolytic Tinplate.** C. Parker. (261–269). **Quantometers and their Use in the Iron and Steel Industry.** E. Lüscher. (270–278). **The Electron Probe Microanalyser and its Application to Steelmaking.** C. Crussard. (279–288). Carbides and ores are analysed as well as metals, and surface defects and inclusions are investigated.

Engineering Aspects of Modern Basic Bessemer Plants. C. Herrmann. (*J. Iron Steel Inst.*, 1957, **185**, Feb., 242–260; Discussion 261–263). [This issue].

Integrated Program Formula for Low Tonnage Steel Mill. D. M. Petty, jun. and R. D. Bradley. (*Western Metals*, 1956, **14**, Feb., 70–72). Improved repair and maintenance is described.

Protection of Arc-furnace Bottoms. F. T. Bagnall, R. H. Baulk, and E. J. Mackay. (*J. Iron Steel Inst.*, 1957, **185**, Feb., 239). [This issue].

The Properties and Uses of Fortiweld Steel. H. F. Tremlett. (*Sheet Metal Ind.*, 1955, **32**, Dec., 885–888). Fortiweld is a low carbon alloy steel treated with boron, and goes a long way towards satisfying the need for high strength, good weldability, formability, and strength at high temperatures. The properties of Fortiweld are discussed together with its working up into fabricated sheet-metal, and its general field of usefulness.—A. H. M.

Symposium on Production and Applications of Alloy and Special Steels. (*Sci. Eng.*, 1956, **9**, Jan.-Feb., 13–15). **1, Alloy Steels—Technical and Economic Background.** E. H. Bucknall. (14–15).

Choice of High-Temperature Alloys. N. J. Grant. (*Metal Progress*, 1956, **69**, May, 81–86). The importance of the crystalline condition and its stability is stressed. An alloy whose crystals can absorb the maximum amount of deformation and retain this without recrystallization to the highest temperature will probably have the highest rupture strength.

Some Aspects of the Use of Molybdenum in Special Steels. C. Gousseland. (*Mét. Constr. Mécan.*, 1956, **88**, Feb., 107–114). The particular advantages conferred on alloy steels by the use of molybdenum are discussed with examples. Molybdenum gives increased mechanical strength together with toughness

in constructional steels, hardness in too steels at elevated temperatures, enhanced corrosion resistance in stainless steels, and increased creep resistance and mechanical properties in high temperature steels.—B. G. B.

Better Stainless. (*Steel*, 1956, **138**, Apr. 16, 57). A new melting process used by Eastern Stainless Steel Corp. to produce special stainless steel without stringers, is mentioned. Selected raw materials are melted in an induction furnace and poured through special slag into the moulds. All stainless steels can be made free of stringer-type inclusions by the process.—D. L. C. P.

Experience with High-Manganese Stainless Steels. R. E. Paret. (*Metal Progress*, 1956, **69**, June, 68–71). The use of two new high manganese stainless steels (AISI types 201 and 202) is discussed. These have very similar properties in sheet form to the normal 18/8 stainless steel. Change in tooling or techniques previously used for 18/8 steels has seldom been required.—B. G. B.

Economies in Making Stainless. G. W. Healy and D. C. Hilty. (*Steel*, 1956, **138**, Mar. 19, 102–106). The results of studies of the effect of oxygen blowing rate in the making of stainless steel are described. In general higher oxygen rates give: (1) shorter oxidation periods; (2) lower oxygen consumption; (3) less oxidation of chromium and other metals; (4) higher bath temperatures.—D. L. C. P.

Stainless Steels. Point of View of the Producer. R. Perrin. (*Mét. Constr. Mécan.*, 1956, **88**, Feb., 117–121). The production of stainless steels to a constant specification, which is essential for clients who subsequently process the steel, is discussed.—B. G. B.

Low Carbon, Low Nitrogen Improve Stainless Properties. F. C. Monkman, N. J. Grant. (*Iron Age*, 1956, **177**, May 31, 67–70). Work on the effect of carbon and nitrogen on the properties of stainless steels is described. It is concluded that the contents of these elements are highly critical factors affecting properties at elevated temperatures.—D. L. C. P.

The New Stainless Steels. D. B. Roach and A. M. Hall. (*Mat. Methods*, 1956, **43**, Apr., 137–152). This is Manual No. 126. High manganese, extra low carbon, wrought and cast precipitation-hardenable grades and ferritic stainless steels for elevated temperature service are reviewed, some account of their treatment given, and their properties tabulated.

Rare Earth Stainless Steels. H. O. Beaver and B. T. Lanphier. (*Mat. Methods*, 1956, **43**, Feb., 96–98). The effects of mischmetal additions are reviewed. The sulphuric acid-resisting grade, a high-temperature valve steel, and effects on mechanical properties and hot working are discussed.

"Alphasil" Grain-oriented Low Loss Transformer Sheet. E. Marks. (*Electrical J.*, 1956, **156**, May, 1466–1468). The development of grain-oriented silicon steel is outlined with an account of a scheme to treble output in Britain.

Influence of Manganese and Carbon on the Properties of W–Cr Non-deforming Tool Steel. I. N. Yamanaka and K. Kusaka. (*Tetsu to Hagane*, 1956, **42**, Feb., 111–116). [In Japanese]. To investigate the influence of Mn and C on the properties of oil-hardening non-deforming tool steel containing C 1·05, W 1·2, and Cr 0·75%, the critical point, Jominy hardenability, austenite transformation curve, quenched and tempered hardness, retained austenite, dimensional changes and toughness were determined.—K. E. J.

Protection of Refractories by Moving Air Curtains. J. H. Chesters, C. Holden, and A. D. Robertson. (*J. Iron Steel Inst.*, 1957, **185**, Feb., 177–200). [This issue].

Continuous Casting of Steel. I. Harter, Jun. (*Iron Steel Eng.*, 1956, **33**, April, 58–61). This article describes the continuous casting process developed jointly by Republic Steel Corp. and the Babcock and Wilcox Co. Details are given of the mould, automatic pouring control, cooling devices, the cross section of the billet, and the possible yields.—M. D. J. B.

A Pneumatic Level Indicator for the Continuous Casting Process. A. G. Grimshaw and B. O. Smith. (*J. Iron Steel Inst.*, 1957, **185**, Feb., 235–237). [This issue].

Observations on the Thermal Conditions of a Continuous Casting Ingot Mould. J. Tischendorf. (*Neue Hütte*, 1956, **1**, Mar., 303–307). In the upper part of the mould heat flow is largely determined by water velocity, the thickness of the walls, and the material of which the mould is made. But these factors become insignificant when the gas layer between ingot and mould exceeds 0·1 mm in thickness. The object of vibrating the mould is to reduce the insulating effect of the gas layer. Pulsation cooling has been shown to be most effective. Circular motion will double the cooling effect; vibration will increase it by 50%.—L. J. L.

Life of Steel Ladles: Some Experiences at Consett Iron Company Limited. W. M. Fern. (*Iron Coal Trades Rev.*, 1956, **172**, Apr. 13, 359–362). Some of the factors affecting the lives of steel ladles are discussed, with special reference to the refractories used. Improvement in brick quality in recent years has doubled ladle life at Consett Iron Co., Ltd., and investigation shows that the important criteria are porosity, permeability, after-expansion, and chemical expansion. In a special trial of andalusite bricks, the increase in life was not sufficient to be economical, and more skulling was observed.—G. F.

Billet Cutting is Made Easy. V. E. Lysaght. (*Iron Steel Eng.*, 1956, **33**, Mar., 134). A brief account of a wet cutting machine installation.

Special Hot-topping Practices. B. M. Shields. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 160–167). The author discusses a number of special hot-topping practices designed to reduce top discard. He deals first with the use of insulating materials as hot-top linings, discussing recent developments showing yield improvements of the order of 3%. More expensive methods which supply heat to the head and show gains of 7–8% are also considered; there are electric-arc and flame hot-topping, and the use of thermit and mouldable exothermic compounds.—G. F.

Influence of Ingot Dimensions on Segregation in Large Rim-steel Ingots. J. F. Elliott, K. R. Mattson, and J. Tatu, Jr. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 142–157). From a study of a series of rimming ingots poured and capped under controlled conditions, the authors summarize the general patterns of segregation encountered in rimming steel. Considerable variation was found from ingot to ingot, maximum segregation occurring in the centre at 75–88% height. The factors primarily influencing the concentration of metalloids at any position were ladle analysis, rimming action quality, and capping practice; ingot dimensions were found to have little effect. Steps to be taken to minimize segregation are outlined.—G. F.

Segregates in Large Steel Blocks. E. J. Pavesic. (*Metal Progress*, 1956, **69**, May, 112). The observation of parallel bands of higher alloy material segregating in tool steel of large cross-section is reported.—B. G. B.

Study on Blowholes in Iron and Steel. II. Composition of Gases in Blowholes. T. Fujii. (*Tetsu to Hagane*, 1956, **42**, Feb., 94–98). [In Japanese]. A vacuum cutting technique is described for collecting gases from blowholes with the minimum of interference from gases evolved by frictional heat. Hydrogen and nitrogen were predominant, the former in non-deoxidized steel and the latter in deoxidized steel; some free oxygen was also found. It is presumed that carbon monoxide is originally present; this decomposes, with fall of pressure, and hydrogen and nitrogen diffuse in from the steel.—K. E. J.

The Preparation of Steels by Electrolysis of Silicates with a Cast Iron Cathode. M. Dodero and R. Mayoud. (*Compt. Rend.*, 1956, **242**, Jan. 4, 124–126). The preparation of 100–200 g lots of ferrosilicon, ferromanganese, and ferrochrome is described.

FOUNDRY PRACTICE

New Horizons in Foundry Progress. H. J. Heine. (*Inst. Brit. Found., Australian Branch, Convention* 1955, 107–122). The use of new alloys, methods, designs, equipment, and materials is reviewed with reference to vacuum practice, high pressure moulding, shell moulding, core shooting, and the CO_2 process. Gating and risering and industrial management are also touched on.

Co-operation Between Engineer and Foundryman on Casting Design. G. Blanc and M. Jaumain. (*Found. Trade J.*, 1956, **100**, Jan. 19, 63–73).

Collaboration between the Designer, Caster and Pattern-maker. R. Dellwig. (*Giesserei*, 1956, **43**, Feb. 2, 71–73). Several examples are cited of the necessity for collaboration at various stages in the production of a casting. A brief mention is made of accidents with cranes.—R. J. W.

Dictionary of Technical Terms used in Pressure Casting. (*J. d'Inf. Tech. Indus. Fonderie*, 1956, July, Supplement).

Coated Abrasive Finishing. C. Perrett. (*Metal Ind.*, 1956 **88**, Jan. 13, 28–31). A review of foundry grinding machines.

A Study of the Influence of Production Equipment on the Cost of a Casting. M. Bednářík. (*Slévárenství*, 1956, **4**, (3), 65–68). [In Czech]. A survey is made of the costs associated with various methods and varying degrees of mechanization of casting, the casting of a drain pipe being used as standard for comparison.—P. F.

Induction Melting. K.-H. Brokmeier. (*Giesserei*, 1956, **43**, Feb. 2, 57–64). A comprehensive review article. The theory of induction heating is outlined and the choice of the type of furnace to be used is considered. The possible uses and limitations are clearly stated, technical, metallurgical and economic viewpoints of the use of this method in the foundry being considered. Applications to the melting of different metals are described, with reference to different types of construction. High, medium, and low frequency furnaces, of trough or crucible designs and also a high vacuum furnace are described.—R. J. W.

Hot-Blast Cupola Practice. W. L. Heinrichs. (*Amer. Found. Soc. Preprint*, 1956, No. 22). The thermal and metallurgical reactions taking place in the cupola are reviewed and discussed with particular reference to the basic hot-blast cupola. A description is given of a hot-blast cupola installed at the Krupp foundry in Essen and operating experiences with this cupola are discussed. The furnace is lined with carbon bricks and operated with a basic slag. Test runs have shown that it can be used continuously if required.—B. C. W.

Service Life of Iron Castings Can be Affected by their Thermal Conductivity. J. A. Davis, H. W. Deem, and H. W. Lownie, jnr. (*Amer. Found. Soc. Preprint*, 1956, No. 26). Data are given on the coefficients of thermal conductivity of five cast irons between 55° and 315° C. The service conditions which can make thermal conductivity an important factor in design and in service life are discussed with reference to some practical examples.—B. C. W.

The Production of Castings from Acid-Resisting Silicon Cast-Iron. J. Hučka. (*Slévárenství*, 1956, **4**, (3), 68–73). [In Czech]. The production technology of castings made from 14–16% Si cast iron is discussed, and the scope and properties of the material as well as of the castings are discussed.—P. F.

Reduction of Waste in Grey Casting by Welding Casting Defects Even in Large Castings. O. Dittmar. (*Giessereitechn.*, 1956, **2**, Jan., 7–9). Several examples of the hot welding at 650° C of large castings (such as an oil sump) are given. Temperatures were measured continuously, and welding time schedules are discussed.—L. J. L.

The Malleablizing of Malleable-Castings in a Gas Atmosphere. K. Roesch and H. Friederichs. (*Giesserei*, 1956, **43**, Apr. 12, 177–180). The chemical–physical processes which take place during gas-tempering are described. The progress made in methods for malleablizing is shown and the practical use of the experimentally developed equilibrium behaviour in the annealing of carbon-bearing iron in a CO–CO_2–H_2–H_2O mixture is described. The most recent developments in the design of furnace plant are described and the economics of gas-malleablizing discussed.—R. J. W.

Oxygen Blowing Rate in Stainless Steel Melting. G. W. Healy and D. C. Hilty. (*J. Met.*, 1956, **8**, Mar., 325–327). By means of bath temperature measurements and calculations of radiation losses and temperature distribution between bath and refractories, the authors have evaluated the heat balance of the oxidizing period in a 1-ton arc furnace experimentally melting stainless steel. The results have also been extrapolated to furnaces of larger size, and graphs illustrating the effect of oxygen input rate on several variables in a 10-ton furnace are given.—G. F.

Moulding Sands. J. Navarro Alcacer and J. A. Andres Jimenez. (*Inst. Hierro Acero*, 1956, **9**, Jan.-Mar., 277–305). [In Spanish]. This is the first part of a systematic survey of Spanish sands. The requirements and methods of study of such sands are first described in detail, and then the results of a study of sixteen (chosen from the twenty-eight available) of the Catalonian region are described and a partly completed data sheet is given for each. Six silica sands are suitable for synthetic mixtures, the rest which are natural bonding sands have low permeabilities and restricted uses. In an appendix, further physical tests are described and dehydration curves for seven of the sands are given. (21 references).—P. S.

A Technical and Mineralogical Study of Some Spanish Moulding Sands. V. Aleixandre Ferrandis and J. Robredo Olave. (*Inst. Hierro Acero*, 1956, **9**, Feb., 118–145. *Special Number*). [In Spanish]. Data obtained in a study of sixteen moulding sands is presented in two parts. The first is a study of the green compressive strength and bulk density of the sands in relation to the mineralogical nature of their bonds and a relationship is shown between these, the minimum bulk density, and maximum green strength. In the second part the results of green permeability tests and size analyses are given. The Carman–Jasson relationship was found to hold with the limits of validity extended to cover bulk densities of 1·45 to 1·60. Deviations from this relationship may be due to high clay contents, irregular grain distribution or accumulated fines. The carbonate content of the sand had no effect on permeability. (21 references).—P. S.

A Sand-drying Drum for Quartz Sand. K. Haake (*Giessereitechn.*, 1956, **2**, Apr., 87). A horizontal sand-drying oven is described and illustrated. Dust is removed by the exhaust gases, and grain size of the sand can be regulated to some extent, depending on the height of the chimney stack.

Green-Sand Casting Finish. R. F. Meader. (*Amer. Found. Soc. Preprint.*, 1956, No. 156). The factors affecting the surface finish on green sand castings are discussed. Those considered include sand grain size and distribution, mould hardness, pouring temperature, facing additives, condition of patterns, cleanliness of sand, flowability of sand, sand moisture, and cleaning methods.—B. C. W.

Cold Process for Resin Coated Foundry Sands. J. E. Bolt. (*Amer. Found. Soc. Preprint*, 1956, No. 169). The advantages of resin-coated sands are summarized and the methods available for producing such sands by coating at room temperature are described. Details are given of the procedures to be followed in preparing resin-coated sands in either low or high speed mullers using the alcohol–water solvent method with dry resin.—B. C. W.

The Effect on the Strength of Quartz Sands Bound with Sodium Silicate of Various Additives and Sodium Silicate Concentrations. J. Czikel and R. Wasner. (*Giessereitechn.*, 1956, **2**, June, 121–124). The results of experiments to determine the optimum quantity and concentration of sodium silicate binders for any given quartz sand are reported. As a first approximation the authors formulate: Optimum sodium silicate additive (%) × average particle size (mm) = 1.

Do's and Don'ts in Hardening Sand with CO_2. J. E. Gotheridge and F. Pursall. (*Foundry*, 1956, **84**, Mar., 128–135). The CO_2 process for hardening moulds and cores is reviewed and discussed. The aspects considered include the effect of sand variables on the strength of hardened cores, the properties of silica-bonded sands, the methods of applying the gas, surface finish, collapsibility and the applications of the process.—B. C. W.

Recent Developments in the CO_2 Process. W. Schumacher. (*Foundry*, 1956, **84**, Jan., 88–93). The results of experiments on the thermal conductivity, collapsibility, and gas evolution of sands hardened by the CO_2 process are presented and discussed in relation to foundry practice. The reuse of sand and practical applications are briefly considered.—B. C. W.

The Application of the CO_2 Sodium Silicate Process in the VEB Foundry "Rudolf Harlass". E. Grohmann. (*Giessereitechn.*, 1956, **2**, June, 130–134). The history of the process is briefly reviewed; practical experience of the process at the Rudolf Harlass Foundry is recounted. Particular attention must be paid to technical and economic problems when using the process.—L. J. L.

The Conversion of Pump Stand Cores from Clay Cores to CO_2 Cores. W. Muhs. (*Giessereitechn.*, 1956, **2**, June, 138–139). The core composition was: 90% quartz sand; 3·5% coal dust, 1·5% binder, and 5% sodium silicate. The manufacture of the cores is illustrated and described in some detail.—L. J. L.

Synthetic Resin Core Binders. L. Chroszcz. (*Giessereitechn.*, 1956, **2**, Apr., 90–92). The manufacture of synthetic resin core binders, drying processes, viscosity and temperature characteristics, safety measures, and engineering problems are explained in non-technical language, and the economic advantages of using these binders are stressed.—L. J. L.

High-Pressure Moulding. Past, Present, and Future. T. E. Barlow. (*Foundry*, 1956, **84**, Mar., 104–109). The development of the high pressure moulding technique is briefly reviewed and the properties of the moulding sands suitable for this process are discussed. The possibility of combining

high pressure diaphragm moulding with CO_2-treated sands for the production of cured moulds at high speed, is considered.

Problems of Moulding Technique in the Manufacture of Machine Castings. J. Racz. (*Giessereitechn.*, 1956, **2**, Apr., 83–86: *Kohászati Lapok* (*Öntöde*), 1955, 180–186). Improvements in moulding technique developed in Hungarian foundries are described. Differences in hardness between parts of a casting were reduced. The production of cast-on fins, and the insertion of cores are discussed.—L. J. L.

Casting of Large and Heavy Steel Castings. V. Batěk. (*Slévárenství*, 1956, **4**, (4), 111–116). [In Czech]. Rationalization of casting methods and the technological basis of pouring castings weighing about 100 tons are reviewed, with special reference to experiences gained in the V. I. Lenin (Škoda) Works in Pilsen.—P. F.

Statistical Controls—A Valuable Tool for Reducing Costs. K. M. Smith. (*Foundry*, 1956, **84**, May, 138–141). The merits, fundamentals, and applications of a statistical foundry control system are discussed in general terms.—B. C. W.

Practical Foundry Application of Statistical Quality Control. R. Martin, Jr. (*Amer. Found. Soc. Preprint*, 1956, No. 53). The foundry problems to which statistical quality control can be applied are briefly considered.—B. C. W.

Quality Control of Investment Castings. C. Yaker. (*Precision Met. Mold.*, 1956, **14**, Jan., 47, 79; Feb., 35–36, 81; March, 36–37, 70–74). The important variables in the various investment casting operations are given together with their effect on casting quality and methods used for their control.—D. H.

Application of Activity Sampling Technique in Iron Foundries. (*Brit. C.I. Res. Assoc., J. Res. Dev.*, 1955, **6**, Dec., 137–140). A short account of operational research studies at 3 iron foundries is presented.—B. G. B.

Know Your Casting Costs. E. Magder. (*Canad. Metals*, 1956, **19**, Apr., 47–51). A review of the advantages of cost accounting in the foundry is presented.

Dust and Fume Extraction in Foundries. J. A. Wilkins. (*Found. Trade J.*, 1956, **100**, May 31, 381–387). The elimination of dust and fumes in the foundry is considered in relation to the Iron and Steel Foundry Regulations, 1953. The aspects covered include mould drying, knocking-out with particular reference to the design of hoods, dressing and fettling, and the separation and disposal of the dust.—B. C. W.

Heat Abatement in the Forge and Foundry. H. Allen. (*Metal Treatment and Drop Forging*, 1956, **23**, June, 243–242). Emissivity figures are given and the treatment of a billet heating furnace is described, also a foundry workshop.

VACUUM METALLURGY

Applications of Vacuum Techniques to the Elaboration and Treatment of Metals. O. Winkler. (*Rev. Soc. Roy. Belge Ing. Indust.*, **1956**, Jan., 17–31). The influence of dissolved gases on the properties of metals and alloys is first described. Techniques used for the vacuum fusion of metals are described with illustrations of commercial equipment. Examples of the change in composition of steels subjected to vacuum melting are given.—B. G. B.

The Application of Vacuum Technology to Metallurgical Research. R. F. Dickerson and E. L. Foster, Jun. (*Vakuum-Techn.*, 1956, **5**, May, 33–38). A general survey is made of the application of vacuum or of reduced pressure to metallurgical research. Apparatus available at the Batelle Memorial Institute is described and illustrated. It comprises furnaces for induction melting, arc melting, and heat treatment, welding chambers, drying cabinets, an X-ray installation, and special metallographical equipment.—L. J. L.

Vacuum Casting of Steel in Large Quantities. (*Iron Coal Trades Rev.*, 1956, **172**, June 22, 1039–1041). Further details are given of the degassing techniques practised at Bochum. The advantages of vacuum casting are enumerated, and figures illustrating the degree of degasification and the resulting improved steel quality are given.—G. F.

Vacuum Melted Metals—An Interim Report. F. T. Chesnut. (*Indust. Heating*, 1956, **23**, Feb., 278–288, 434–440; Mar., 522–534, 646–651). The development of vacuum melting furnaces is reviewed and the chief types are described. Applications of the process in the U.S. are given with examples, and improvements in properties obtained by vacuum melting are shown.—A. D. H.

Vacuum Casting Forging Ingots. (*Steel*, 1956, **138**, June 4, 112). Plans for vacuum casting large forging ingots at the Duquesne (Pa.) Works of U.S. Steel Co. are announced. Ingots up to 150 tons are planned and will be used for shafting, bearings, and aeroplane parts.—D. L. C. P.

Industrial Use of Steel De-Gasification Under Vacuum, Especially on Large Forging Ingots. A. Tix. (*Stahl u. Eisen*, 1956, **76**, Jan. 26, 61–68). The author discusses continuous degasification and the pouring of heavy forging ingots under vacuum to eliminate flakes and non-metallic inclusions, avoiding the use of expensive heat treatment to remove hydrogen. He describes equipment required for pouring under vacuum, and gives an account of the behaviour of the poured stream as compared with normal pouring in air. Air- and vacuum-poured steels are compared. The effects of degasification on structure, segregation, porosity, flaking susceptibility, and mechanical properties are reviewed, and statistical evaluation of the ductility of radial test pieces concludes the account.

Methods and Technology of Metal Degasification. W. Espe. (*Vakuum-Techn.*, 1956, **5**, May, 39–53; June, 69–82). Layers of gas and steam adsorbed on glass are readily removed by heating *in vacuo*, to 400–500° C. Many complicated methods are used to degasify metals and a comprehensive review is given of these. Causes, quantities, and types are considered, and degasification during vacuum smelting and annealing of components in hydrogen or high vacua are discussed in detail. The second part deals with degasification of valve electrodes during pumping.

REHEATING FURNACES AND SOAKING PITS

Furnaces Whip Scale Problem. (*Steel*, 1956, **138**, June 25, 86). The new design of forge furnaces and burners installed at Webb Forging Co., Mich., is described. The burners are sited to give an even flame cover on the floor of the furnace and the elimination of scale on the heated stock is attributed to this. In the burner the oil mist meets primary air set in rotation by vanes; secondary air gets similar agitation. The furnaces are cheap to run, speedy and versatile.—D. L. C. P.

Measurement of Ingot Temperature During Heating in a Soaking Pit. R. Rhone and M. Guillaume. (*Centre Doc. Sidér., Circ. Inform. Techn.*, 1956, **13**, No. 6, 1163–1188). The results given and discussed here concern the reheating of 4·5 ton ingots in a multi-cell soaking pit heated by mixed coke-oven and blast-furnace gas. The way in which the internal temperature of an ingot increases with time during heating is studied as a function of the various characteristics of the ingot and of the running of the furnace. Temperature measurements were made at 7 places inside the ingots.—T. E. D.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Spang-Chalfant Installs Automatic Mechanized Heat-Treating Equipment. (*Iron Steel Eng.*, 1956, **33**, Mar., 138).

Selection of Steel for Heat Treatment. K. G. Morrison. (*Australasian Eng.*, 1956, **48**, Feb., 64–67). A discussion of the SAE steels with the example of the choice for the manufacture of an automobile steering knuckle is given. Heat treatment is discussed at some length, and other uses briefly considered.

Principles of Heat Treatment of Steels. R. Smith. (*Australasian Eng.*, 1956, **48**, Jan., 61–71). Phase transformations are considered, and pearlite, bainite, and martensite are discussed. Practical heat treatment processes are developed in outline from the principles described.

Heat Treatment Equipment. (*Automobile Eng.*, 1956, **46**, June, 246–247). An account of the use of Corrtherm elements in furnaces for various purposes.

Heat-Treatment Technique. J. W. Oppy. (*Australasian Eng.*, 1956, **48**, Mar., 64–67). A series of brief notes on the treatment of steels used in general engineering. Stress-relieving, preheating, quenching, tempering and martempering, surface hardening, nitriding, and case carburizing are considered and then various steels are reviewed and treatments tabulated. Carbon steels, non-shrink steels, high-carbon high-chrome steels, shock-resisting steels, hot-work steels, and die-casting and plastic moulding dies are all briefly discussed.

Heat-Treatment Technique for Constructional Steels. V. A. Sharp. (*Australasian Eng.*, 1956, **48**, Apr., 63–66). Furnaces and quenching procedures are mainly considered.

Engineered Heat Treating Equipment—A Key to Improved Metallurgical Products. R. W. Brown. (*Indust. Heating*,

1956, **23**, Feb., 240–246). The author describes the slab heating and heat-treatment furnaces used for pilot-plant scale production of special-purpose steels and alloys in a new development laboratory of the Westinghouse Electric Corporation, Pa.—A. D. H.

Steels and Their Treatment for Engineering. J. G. Ritchie. (*Australasian Eng.*, 1956, **48**, Apr., 57–62). A non-technical account of properties, methods of testing, heat-treatments and their effects, and some of the structures produced is given.

Performance of Rectangular Bell Type Annealing Furnaces. R. R. Lapelle. (*Iron Steel Eng.*, 1956, **33**, Feb., 122). This article describes the performance of a bell furnace for long cycle and spheroidized annealing of high carbon and tool steel bars.—M. D. J. B.

Coreless Induction Furnace. K. Scherzer and F. S. Leigh. (*Iron Steel*, 1955, **28**, Dec., 669–672; 1956, **29**, Mar., 105–108). The differences between high-frequency and mains-frequency furnaces are outlined and the design of the latter is discussed in terms of current penetration, power factor, electrical efficiency, minimum furnace size, furnace coil and body and electrical layout. Examples of uses are then illustrated and discussed and operating data and economics summarized.

The Mains Frequency Coreless Induction Melting Furnace. K. Scherzer. (*Metallurgia*, 1956, **53**, Apr., 171–174). Practical considerations and applications of this technique are discussed. Examples of equipment designed for melting cast iron and for steel are considered.—B. G. B.

Heat Treat Line for Aircraft Steels. W. J. Hoppe, L. R. Fitch. (*Steel*, 1956, **138**, May 14, 124). The new plant at Boeing Airplane Co., for heat treating aircraft-quality steel bars and other long shapes is described. A vertical travelling elevator furnace can move over 3 quench tanks (martempering oil, and water); a draw furnace is adjacent. The electric furnaces have a charge space 5 ft diameter and 14 ft high.

Low Alloy Steels Resistant to Heat and Their Thermal Treatment. G. Delbart and A. Constant. (*Métaux–Corrosion–Indust.*, 1956, **31**, June, 251–264). A review of factors influencing creep resistance and in particular the influence of thermal treatment on creep resistance of low alloy steels is first made. A number of results obtained during the study of the creep of samples tempered under different conditions is discussed.

A Furnace Monitor for the Protection of Automatically Controlled Electrically Heated Industrial Furnaces. Sachs. (*Draht, English Ed.*, 1955, Oct., 35–36). An account of the Limitherm-Ofenwächter and its operation.

New Furnace Combines Annealing, Vacuum Degassing. (*Iron Age*, 1956, **177**, Apr. 12, 102–103). The furnace described is used for annealing and vacuum degassing steel rings used in electronic power tubes. Furnace capacity is 1000 lb; gas pressure is maintained below 1 micron; temperature reached is 1850° F. Cost and quality advantages are obtained over previous methods.—D. L. C. P.

Electric Furnaces for the Heat Treatment of Wire. (*Wild Barfield Heat Treatment J.*, 1956, **5**, March, 2–5). The more commonly used electric furnaces for the batch or continuous heat treatment of wire are briefly described.—D. H.

Studies on Heat-treating of Silicon Steel Sheets, I. T. Takei, H. Mizuno, and K. Haga. (*Rep. Sci. Res. Inst.*, 1955, **31**, Nov., 363–371). [English summary]. The object was the production of an insulating film for minimizing eddy currents in laminations. Annealing in hydrogen at 1200° before or at 1100° after production of the film gives optimum magnetic properties.

Controlled Atmosphere Heat Treating and Equipment. F. E. Harris. (*Metal Treating*, 1956, **7**, Mar.-Apr., 4, 6–7, 31–32; May-June, 8–10, 30). A batch-type furnace is described in detail with illustrations of valves, doors, etc. The Dow Model J-800 furnace is shown and diagrams showing dew-points and carbon dioxide pressures in equilibrium with carbon content are given. The model HA-400 is also shown, working on the same " Sealed-Cycle " principle.

Control of Controlled Atmospheres. D. J. Schwalm. (*Metal Progress*, 1956, **70**, July, 99–102). A description of the Lo-Dew endothermic gas generator is given. This unit can produce atmospheres with a wide range of composition. The control of gas atmospheres is discussed and the advantages of the infra-red CO_2 recorder over dew point measurements for control are considered.—B. G. B.

Temperature Control of Heat Treating Furnaces. R. M. Sills. (*Steel*, 1956, **138**, (**1**), Feb. 13, 108–112); (**2**) **Thermocouples.** (Feb. 20, 135–139); (**3**) **Control Instruments.** (Mar. 26, 130–132); (**4**) **Control Elements.** (Apr. 2, 110–114); (**5**) **Control Systems.** (Apr. 30, 112–117); (**6**) **Special Systems.** (May 7, 116–120).—D. L. C. P.

Variation of the Properties of Spring Steels as a Function of the Heat-Treatment and Surface Finish. M. Pujol Roig. (*Inst. Hierro Acero*, 1956, **9**, Feb., 183–198, *Special Number*). [In Spanish]. After a brief review of the characteristics and requirements of spring steels, an experimental study of the fatigue behaviour of a carbon steel (0·6% C, 0·7% Mn, 0·28% Si, P and S less than 0·025%) is described. Various heat-treatments were given, and it is concluded that (*a*) austempering and martempering give better fatigue resistance than the classical heat-treatment for a given hardness level, (*b*) polishing or phosphating improve resistance to fatigue, (*c*) sand-blasting is prejudicial. The micrographs reproduced indicate a zone of decarburization in the specimens in the as-received state. (11 references).—P. S.

Normalizing and Quench and Temper Heat Treatment of Steel Products. J. MacGregor. (*Iron Steel Eng.*, 1956, **33**, May, 108–115). The author describes the quench and temper process to produce high strength casing from plain carbon or comparatively low alloyed grades of steel. The heat treatment line described has a processing capacity of about 5½ tons per hour of a variety of sizes from 5½ to 9⅝ in. dia. tubing.

The Optimum Boron Content for Hardenability. J. C. Shyne, E. R. Morgan, and D. N. Frey. (*Trans. Amer. Soc. Metals*, 1956, **48**, 265–278). The correlation, in terms of " effective " rather than total boron content, was made on a series of high purity iron–carbon–boron alloys. The maximum boron hardenability effect was obtained in an alloy containing 0·00033% effective boron. A method for determining the effective boron is described.—E. E. W.

Modern Case-Hardening Processes. P. F. Hancock. (*J. B. Met. Soc.*, 1956, **36**, Mar., 360–381). Carburizing, gas-carburizing, case characteristics, furnaces for gas-carburizing, carbo-nitriding, and induction and flame hardening are discussed in turn, with paragraphs on metallurgical considerations and practical applications.

Get Top Quality Carburizing with Zone Control. H. C. Harris. (*Iron Age*, 1956, **177**, June 21, 107–109). The use of zone controlled gas carburizing for transmission and rear axle gears at Mack Mfg. Corp., N.J., is described. Zones are: 1, heating; 2 and 3, natural propane and carrier gas; 4 and 5, carrier (RX generator) gas; carefully metered air introduced to zone 5. A maximum of 0·8% carbon is maintained at the surface of the carburized case.—D. L. C. P.

Study of Deformation During Surface Hardening by High Frequency Induction Heating. J. P. Gouyet. (*Métaux–Corrosion–Indust.*, 1956, **31**, Apr., 188–199). Tests carried out on a 0·4% C, 0·37% Si, 0·59% Mn steel are described. Six different shapes of sample were used and the differences in the extent of deformation, temperatures of the sample and tempered zones are described. The thickness of the sample has the greatest influence on the extent of deformation. The deformation increases with quantity of martensite formed in the interior of the specimen and decreases with quantity of residual martensite. Detailed tables showing the full experimental results are given.—B. G. B.

Induction Setup Hardens Teeth by Pairs. (*Iron Age*, 1956, **177**, June 14, 110). A machine which automatically hardens teeth on typewriter escapement racks is described. Teeth are induction heated and quenched 2 at a time; little distortion results.—D. L. C. P.

Modern Annealing Furnaces for Narrow Strip. Z. Wusatowski. (*Hutnik*, 1955, **22**, (7/8), 258–265). A variety of annealing furnaces are described. The advantages of continuous furnaces for the treatment of normalized strip are stressed.—W. E. & A. P. M.

Effect of Section Size on the Quenching Sensitivity of Grey Cast Iron. A. D. Lamb. (*Brit. C.I. Res. Assoc., J. Res. Dev.*, 1956, **6**, Apr., 184–194). Experiments carried out on 2·1 in. and 4 in. dia. bars of ordinary iron and two alloyed cast irons to study the effect of section size on hardenability are described.—B. G. B.

The Influence of Alloying Elements on the Patenting of Steel Wire. Z. Steininger. (*Hutnik*, 1955, **22**, (9), 306–313). The significance of TTT curves in the patenting process is discussed, followed by an analysis of the effect of C, Mn, Si, S, P, Cr, Ni, Cu, Al, O_2, and N_2 on the relevant temperature region (500–600° C). The presence of normal percentages of Ni, Mn, Si, and most of the other elements does not necessitate

any adjustments in the patenting process; however, the presence of Cr, especially where high Cr contents are required for hardenability or corrosion resistance, changes the TTT curve sufficiently for alterations in normal patenting practice to be necessary.—W. E. & A. P. M.

FORGING, STAMPING, DRAWING, AND PRESSING

Investigations of the Forging Qualities of Work-resistant Steel. G. Juretzek and R. Kuhn. (*Neue Hütte*, 1956, **1**, July, 390–399). A statistical evaluation showed that fewer surface cracks occurred during preliminary forging of a high speed steel if the ingots were repeatedly reheated. Hot notch bar tests showed that interior cracks occurred in high speed steel ingots after forging by a 2·5 ton hammer. The use of smaller ingots is advocated. Optimum forging temperatures for a number of steels have been determined by means of notched bar tests.—L. J. L.

Compressor Blades—Their Application to Forging Design and Manufacture. R. H. Daniels. (*Metal Treatment and Drop Forging*, 1956, **23**, Mar., 87–90). Gauges, dies, and inspection are described as well as design and forging.

On the Heterogeneities of Steel Forgings and the Resultant Mechanical Properties. E. A. Loria. (*Blast Furn. Steel Plant*, 1956, **44**, Mar., 315–321, 330). The segregations which occur in ingots during cooling are described and their influence on the production of sound forgings is discussed in some detail.

Fabricated Metal Parts, Design and Selection Factors. (*Mat. Methods*, 1956, **43**, Feb., 121–136). A new manual replacing that of Dec. 1950. Methods of fabrication of parts are discussed, and the main features of each process tabulated. The manual is intended to assist in the choice of the best process for any shape or part required.

Get Rid of Kinks by New Tube Forming Methods. W. G. Patton. (*Iron Age*, 1956, **177**, Apr. 19, 95–98). The shaping of square and rectangular sectioned metal tubes for car frame components is described. Expandable tools are shown which are used to taper the tubing; smooth bends are made using hydraulically operated articulated expanding mandrels.

Mechanical Scarfing: The Rush is On. G. H. Such. (*Steel*, 1956, **138**, April 2, 104–108). The extent of mechanical flame scarfing of slabs and other sections is considered and particular installations are mentioned; there are 55 in U.S. and the practice is growing.—D. L. C. P.

Press Tools for Accurate Concentricity. (*Mech. World*, 1956, **136**, Feb., 78–80). Brief details are given of a simplified version of a compound press tool for the production of small gears where concentricity accuracies of 0·001–0·002 in. are required.—D. H.

The Toolmaker and the Electron Microscope. J. Lomas. (*Machinery Lloyd*, 1956, **28**, July 21, 81–82).

Mechanised Handling System Automates Forge Furnace. (*Indust. Heating*, 1956, **23**, Feb., 402–404). A description is given of a machine for handling blanks from a stack, passing them through a furnace, and feeding them to a press.—A. D. H.

New Type Press for Cold Extrusion. O. May. (*Sheet Metal Ind.*, 1955, **32**, July, 528–530, 536). The "Maypres" has a toggle system operating in tension and is suitable for the production of shallow components of complex shape.—A. H. M.

Precision Swaging and Plant Therefor. K. W. Michler. (*Metall*, 1956, **10**, Apr., 293–297). Recently developed hot and cold swaging machines are described and some of the products made on them are illustrated. Data on dimensional accuracy of products and some typical manufacturing times are quoted.—J. G. W.

One Man Pulls Strings on Giant Scrap System. H. Chase. (*Iron Age*, 1956, **177**, April 12, 104–105). The system of handling scrap from presses of Chrysler's Automotive Body Div. is described. Conveyors feed the baler which presses 700 lb bales. The central control station is aided by signal lights, mirrors, and television.—D. L. C. P.

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any adjustments in the patenting process; however, the presence of Cr, especially where high Cr contents are required for hardenability or corrosion resistance, changes the TTT curve sufficiently for alterations in normal patenting practice to be necessary.—W. E. & A. P. M.

FORGING, STAMPING, DRAWING, AND PRESSING

Investigations of the Forging Qualities of Work-resistant Steel. G. Juretzek and R. Kuhn. (*Neue Hütte*, 1956, **1**, July, 390–399). A statistical evaluation showed that fewer surface cracks occurred during preliminary forging of a high speed steel if the ingots were repeatedly reheated. Hot notch bar tests showed that interior cracks occurred in high speed steel ingots after forging by a 2·5 ton hammer. The use of smaller ingots is advocated. Optimum forging temperatures for a number of steels have been determined by means of notched bar tests.—L. J. L.

Compressor Blades—Their Application to Forging Design and Manufacture. R. H. Daniels. (*Metal Treatment and Drop Forging*, 1956, **23**, Mar., 87–90). Gauges, dies, and inspection are described as well as design and forging.

On the Heterogeneities of Steel Forgings and the Resultant Mechanical Properties. E. A. Loria. (*Blast Furn. Steel Plant*, 1956, **44**, Mar., 315–321, 330). The segregations which occur in ingots during cooling are described and their influence on the production of sound forgings is discussed in some detail.

Fabricated Metal Parts, Design and Selection Factors. (*Mat. Methods*, 1956, **43**, Feb., 121–136). A new manual replacing that of Dec. 1950. Methods of fabrication of parts are discussed, and the main features of each process tabulated. The manual is intended to assist in the choice of the best process for any shape or part required.

Get Rid of Kinks by New Tube Forming Methods. W. G. Patton. (*Iron Age*, 1956, **177**, Apr. 19, 95–98). The shaping of square and rectangular sectioned metal tubes for car frame components is described. Expandable tools are shown which are used to taper the tubing; smooth bends are made using hydraulically operated articulated expanding mandrels.

Mechanical Scarfing: The Rush is On. G. H. Such. (*Steel*, 1956, **138**, April 2, 104–108). The extent of mechanical flame scarfing of slabs and other sections is considered and particular installations are mentioned; there are 55 in U.S. and the practice is growing.—D. L. C. P.

Press Tools for Accurate Concentricity. (*Mech. World*, 1956, **136**, Feb., 78–80). Brief details are given of a simplified version of a compound press tool for the production of small gears where concentricity accuracies of 0·001–0·002 in. are required.—D. H.

The Toolmaker and the Electron Microscope. J. Lomas. (*Machinery Lloyd*, 1956, **28**, July 21, 81–82).

Mechanised Handling System Automates Forge Furnace. (*Indust. Heating*, 1956, **23**, Feb., 402–404). A description is given of a machine for handling blanks from a stack, passing them through a furnace, and feeding them to a press.—A. D. H.

New Type Press for Cold Extrusion. O. May. (*Sheet Metal Ind.*, 1955, **32**, July, 528–530, 536). The "Maypres" has a toggle system operating in tension and is suitable for the production of shallow components of complex shape.—A. H. M.

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Testing the Alignment of Rolling Mill Housings. M. J. Puttock and J. W. Bell. (*Australian Machinery*, 1956, **9**, May, 13, 15, 17, 19, 21). The methods used by the National Standards Laboratory to check the alignment of two strip mills, one hot and one cold, of single pass type are described in detail.

Steel Castings for Rolling Mill Couplings. (*Edgar Allen News*, 1956, **35**, June, 117–119). An account is given of the "Holset" coupling and the parts are illustrated.

Analysis of the Rational Design of Profiles for Rolled Steel. B. G. Lozhkin. (*Izvestiya Akademii Nauk SSSR, O.T.N.*, 1956, No. 1, 137–149). [In Russian]. Problems of design of

rational shape of profiles of a constant cross-section are discussed in relation to their weight and the price of steel.

The Reversing Hot Strip Mill—Its Place in the Steel Industry. D. Lyle. (*Iron Steel Eng.*, 1956, **33**, April, 83–89). The author shows that where limited tonnages (500,000 tons/year) are to be produced in carbon steels or special steels, the reversing hot strip mill has certain definite advantages—notably a lower capital cost.—M. D. J. B.

On the Experimental Cold Strip Mill (I). K. Nakamura and H. Takahashi. (*J. Mech. Lab.*, 1956, **10**, Mar., 47–52). An experimental cold strip mill is described. It is a simple stand, 4-high, 4 in. mill, with 3·2 in. dia. workrolls and 8·8 in. back-up rolls, reducing at appr. 80, 100, and 120 ft/min, with 3·6 tons front and 1·8 back tension. The mill can be run as a Steckel. Instruments are of the strain gauge type.

Application of Power Data in Selection of Strip Mill Drives. A. F. Keynon. (*Iron Steel Eng.*, 1956, **33**, April, 63–70). The author reviews well-established methods of power calculation to determine the expected motor loading for particular schedules for cold strip rolling. A method is devised of graphically showing the results of these calculations and indicating the effects of various combinations of strip width, starting and finished strip thickness, and rolling speeds.

Some Factors Influencing the Design of Modern Electric Rolling Mill Drives. H. S. Brown and J. C. Easton. (*West Scotland Iron Steel Inst.*, Paper No. 487, Feb. 17, 1956). In the first part of the paper the authors deal with some of the factors involved in the design of modern rolling mill drives and discuss the following points: general rise in standards, capital and running costs, improved mill operation, and new achievements. In the second part typical examples of bloom mills, rod and bar mills, and cold mills are described to illustrate these points.—L. E. W.

Report on Standardization of Additional A.I.S.E. Mill Motor Frames. M. B. Antrim. (*Iron Steel Eng.*, 1956, **33**, Feb., 55–58). This paper gives the results of the A.I.S.E. Mill Motor Committee's work on developing a larger mill motor frame required by the steel industry.—M. D. J. B.

MACHINERY FOR IRON AND STEELWORKS

Locomotives for Steelworks. Rolls Royce/B.T.H. Diesel-Electric Equipment. (*Elect. Rev.*, 1956, **158**, May 4, 725–726). A description is given of the new 'Janus' 400 h.p. diesel-electric shunting locomotive made by the Yorkshire Engine Co.—L. D. H.

Use of Castings in a Modern Iron and Steel Works. W. F. Cartwright. (*Found. Trade J.*, 1956, **100**, June 14, 443–450). The applications of ferrous and non-ferrous castings (other than rolls and ingot moulds) in a modern iron and steel works are tabulated and discussed. The economics of castings as compared with weldments are considered and the factors affecting the choice of a ferrous material for a particular job are reviewed together with some practical examples. The applications of non-ferrous castings are almost entirely restricted to their use as bearings.—B. C. W.

WELDING AND FLAME-CUTTING

Welding Processes. (*Iron Age*, 1956, **177**, Apr. 26, 94–95). The main welding processes are classified, and the characteristics of each briefly described.—D. L. C. P.

Welding Materials. (*Iron Age*, 1956, **177**, Apr. 26, 96–100). Suitable welding processes are recommended for various base metals and alloys. Tables specify welding materials for a range of metals, and list U.S. suppliers.—D. L. C. P.

Welding Processes and Welding Machines. H. von Hofe. (*Schweissen u. Schneiden*, 1956, **8**, June, 182–186). Welding research carried out in Germany is compared with work done in other countries. The different types of welding methods, gas welding and flame cutting, arc welding, resistance welding, and their problems and equipment, are discussed.—U. E.

A New Welding Alloy with High Abrasion Resistance. T. Norén and T. Hellerström. (*ESAB Revue*, 1956, No. 1, 13–20. French Edn.). The development of the electrode OK H13 is described with an account of its properties and uses. The metal deposited has the composition 0·7% C, 4% Si, 0·4% Mn, 2% Cr.

Mild Steel Electrodes for Gas Metal-Arc Welding in Carbon Dioxide. J. D. Carey and R. D. Mann. (*Welding J.*, 1956, **35**, June, 556–559). An investigation is described in which six widely used electrodes are tested. It is shown that killed and semi-killed steel produce higher quality welds than rimmed steel using both carbon dioxide and argon-oxygen gases.—U. E.

Selection of Stainless Steel Electrodes for Trouble-Free Welds. R. D. Thomas. (*Metal Progress*, 1956, **70**, July, 73–76). The welding of AISI type 347 stainless steel, which is stabilized with 1% niobium, is discussed. Welding cracks can be avoided by using an electrode which gives a weld containing a small amount of ferrite. The welds require heat treatment to prevent embrittlement in service.—B. G. B.

Consumable-Insert Technique for Pipe Welding. R. D. Thomas. (*Mech. Eng.*, 1956, **78**, Feb., 145–149). A new method of pipe welding is described in which the root pass weld of smooth uniform contour, offering little resistance to fluid flow is formed by the use of a consumable ring insert and the inert-gas tungsten arc welding torch.—D. H.

The Economic Importance of Welding. K. Riess. (*Schweissen u. Schneiden*, 1956, **8**, June, 178–182). It is shown that in Germany (Western) about 20 mill. tons of steel are being welded or flame cut, judging from an electrode production of about 70,000 t/year. Some practical applications of welding to structures, such as bridges, or ships and the repair of a 1000-PS steam engine cylinder by welding are described.—U. E.

Welding in the Maintenance and Repair of Hydro-Electric Turbines. K. C. Davidson. (*Australasian Eng.*, 1956, **48**, Jan., 58–60). Applications to Pelton buckets and needles are described.

Protection of Welding Operatives. (*P.A.C.T.*, 1956, **10**, June, 234–235). A helmet with a double window, and a screen with a system for raising the glass are mentioned in this brief article.—T. E. D.

New Times, New Formulæ. A Revolution in the Protection of Arc-Welders. A. Ferire and R. Babault. (*P.A.C.T.*, 1956, **10**, June, 235–238). The Polaro-Métal optical system for incorporation in welding masks is described and its advantages are examined. It consists of a metallized glass or plastic base, a set-up of two filters, functioning by polarization, and allowing the regulation of opacity, and an uncoloured or coloured plastic protector.—T. E. D.

Acetylene Generators for the Workshop. E. Zorn. (*Schweissen u. Schneiden*, 1956, **8**, July, 250–252). The selection of correct generator size and operation are discussed. Acetylene coats are calculated.—U. E.

Effect of Solubility of Alloying Elements upon Weld Hot Cracking. B. I. Medovar. (*Avtomaticheskaya Svarka*, 1955, **8**, (2), 79–90). Weld hot cracking is examined in the light of equilibrium diagrams and correlated with limited range or absence of solid solubility with eutectic formation. Large amounts of eutectic, and immiscibility, may equally prevent hot shortness. Trials with Cr, V, Cu, Si, W, Mn, B, Bi, and Pb are quoted in support.

Effect of Moisture in the Coatings of Low Hydrogen Iron-Powder Electrodes. D. C. Smith, W. G. Rinehart, and K. P. Johannes. (*Welding J.*, 1956, **35**, 313s–322s). The paper gives information on the rate of moisture adsorption under various conditions of temperature and relative humidity, the redrying characteristics, the effect of moisture in producing porosity in the weld metal and finally its effect in producing cracking in the weld metal and fusion zone.—U. E.

Fatigue Strength of Welds in Low-Alloy Structural Steels. J. E. Stallmeyer, G. E. Nordmark, W. H. Munse, and N. M. Newmark. (*Welding J.*, 1956, **35**, June, 298s–307s). Fatigue tests have been conducted on full-scale butt welds and fillet welds in low-alloy steel plates with stress applied either parallel to or perpendicular to the direction of welding. Little difference in fatigue strengths was observed.—U. E.

Electronics and High Productivity in the Heating and Joining of Metals. F. L. Gladwin. (*Wild Barfield Heat Treatment J.*, 1956, **5**, March, 10–15). The practical applications of the induction heating process are briefly mentioned.—D. H.

Behaviour of Welded Pressure Vessels in Agricultural Ammonia Service. T. J. Dawson. (*Welding J.*, 1956, **35**, June, 568–574). The stress corrosion cracking phenomena encountered in welded pressure vessels used for ammonia storage or transport are discussed. It is shown that only stress relieved pressure vessels should be used for this purpose.—U. E.

Soldering and Brazing of Metallurgical Materials. R. C. Jewell. (*J.B. Met. Soc.*, 1956, **36**, June, 383–403). The distinction between soldering and brazing is considered and subdivision into low and high temperature brazing and soft

and hard soldering are proposed. Principles, methods, fluxes, and materials are then discussed, with illustrations of installation for BF_3 brazing, of finished parts, and of micro-structures.

Nickel–Manganese Brazing of Steel. R. A. Gustafson. (*Welding, Metal Fab.*, 1956, **24**, August, 290–291). The use of nickel–manganese material in wire form for brazing high-strength joints in most types of steel including stainless steels and cobalt-base alloys is illustrated.—U. E.

New Kinks in Brazing. P. D. Johnson. (*Steel*, 1956, **138**, May 21, 114–116). Recent developments in brazing techniques and factors of importance in developing new brazing alloys and fluxes are considered. The use of copper and copper oxide pastes on tungsten carbide tips, steel, and stainless steel, and for bridging joint gaps is described. Applicators and brazing furnaces are considered. Copper alloys and lithium additions for brazing compounds are also mentioned.

Brazing in a Vacuum. J. H. Newitt. (*Steel*, 1956, **138**, June 4, 107–108). The processes of vacuum-purge atmosphere brazing are described and the advantages of each considered. Both methods give clean, bright homogeneous joints with high strength; with stainless steels, bonds can approach the strength of the parent metal.—D. L. C. P.

Choose the Light-Brazing Method. P. D. Johnson. (*Steel*, 1956, **138**, Apr. 16, 106–113). The following methods of brazing are described: torch; gas machine; furnace; induction; salt bath; dip. Brazing metals, fluxes and atmospheres are also considered.—D. L. C. P.

Braze Strong Joints with Self-Fluxing Alloys. D. A. Canonico, N. Bredzs, and H. Schwartzbart. (*Iron Age*, 1956, **177**, June 14, 98–99). The use of self-fluxing lithium-bearing brazing alloys is described. Silver and copper alloys containing 1% lithium have been used. The lithium has a high deoxidizing ability and a remarkable tendency to reduce the surface tension of molten metals. Steel, nickel, and cobalt base alloys, ceramics and titanium can be joined, often without reducing atmosphere. Absence of corrosive fluxes is advantageous to quality and process methods.—D. L. C. P.

Brazing Catches Up. (*Steel*, 1956, **138**, Mar. 26, 126–129). The advantages of brazing, and examples of applications of the various methods are given.—D. L. C. P.

Advances in Metal Cutting. J. Lomas. (*Machinery Lloyd, European Edn.*, 1956, **28**, Sept. 8, 51–53). A brief review of recent developments.

Oxygen Cutting. V. Trunschitz. (*Schweisstechn.*, 1956, **10**, Apr., 57–59; May, 67–71). Oxygen cutting of mild and alloy steels is discussed with special reference to cutting width, hardening of the cutting edges, and removal of the hardened zone. Powder cutting is then described and the use of the powder gouge with, finally, a description of torches and methods of cutting.—U. E.

MACHINING AND MACHINABILITY

Machine Research and Its Impact on Speeding Production. D. A. Oliver, T. S. Lister, M. D. Kinman, and D. Fitzgeorge. (*J. Inst. Prod. Eng.*, 1956, **35**, Apr., 253–273). The design of modern machine tools and the understanding and development of new machining techniques are discussed. The machining of high tensile alloys (including steels) of the type used in aircraft construction is particularly considered.—B. G. B.

The Influence of Material, Machine and Tool on the Surface Quality of Gear Tooth Faces. Technique of Measurement and Surface Roughness of Tooth Faces. W. Hagen. (*Z.V.d.I.*, 1955, **97**, Sept. 1, 849–859; Sept. 21, 956–959). Surface roughness was measured by means of replicas microscopically and interferometrically. It was shown that, in marine gearing, tool marks rapidly disappear after a short running period. Further micrographs and attempts at measurement are given in the second article but it is concluded that present methods do not allow of an absolutely exact characterization.—J. G. W.

Effects of Heat Treatment of Constructional Steels on Machinability, Cutting Strength and Performance. H. Opitz and G. Weber. (*Forschungsberichte des Wirtschafts- und Verkehrsministeriums Nordrhein-Westfalen*, 1956, No. 215, pp. 70). Heat treatments are summarized and the microstructures illustrated for various alloy steels, followed by methods and results of tests.

The Relation Between Grinding Conditions and Thermal Damage in the Workpiece. R. S. Hahn. (*Trans. Amer. Soc. Mech. Eng.*, 1956, **78**, May, 807–812). The author has shown (*a*) the tendency for heat checks and cracks to form in a workpiece is dependent on work speed, (*b*) the durability of the cutting edge of a tool is affected by work speed during sharpening. Based on the rubbing grain hypothesis, the 'theory of heat conduction' has been applied to the grinding process to show that lower surface temperatures occur when grinding is carried out at high work-surface speed.—D. H.

The Use of Tungsten Carbide in the Sheet-metal Industry. B. Elliott and J. Evans. (*Sheet Metal Ind.*, 1955, **32**, Nov., 813–821). The authors discuss what is being achieved by much higher production runs, where components are produced in millions with one die set-up.—A. H. M.

Alloy Steels Extend Machine Tool Service Life. R. T. Hook. (*Iron Age*, 1956, **177**, Apr. 26, 101–103). The characteristics of 3 nickel alloy steels are given; it is explained how these are used for various components of machine tools to give the maximum precision and service life according to conditions.

Spheroidal-graphite Cast Iron Dies and Tools for the Sheet-metal Industries. A. B. Everest. (*Sheet Metal Ind.*, 1955, **32**, Nov., 805–812). The advantages of cast iron tools are discussed together with aspects of development and properties of spheroidal-graphite cast iron. The successful use of S.G. iron is illustrated by a wide range of examples.—A. H. M.

The Wear of Cast Iron Machine Tool Slides, Shears and Guideways. H. T. Angus, D. Marles, and M. H. Hillman. (*Brit. C.I. Res. Assoc., J. Res. Dev.*, 1955, **6**, Dec., 72–135). The results are given of an extensive study of the slides of some thirty machine tools all of which were in industrial operation when the examination was made. The influence of microstructure and phosphorus content of the iron on the wear resistance is considered.—B. G. B.

Titanium-carbide Based Hard Metals for High Temperature Applications. (*Machinery*, 1956, **88**, Jan. 6, 29–34). A range of materials known as W.Z.-alloys has been developed which comprise titanium carbide with nickel–chromium or nickel–chromium–cobalt as a binder. Four typical alloys with proportions varying from 75% to 35% of titanium carbide are discussed.—M. A. K.

Effect of Liquid Honing on the Service Performance of Steel. E. A. Satel and M. A. Elizavetin. (*Vestnik Mashinostroeniya*, 1955, **35**, (2), 51–55). A pump for the handling of abrasive suspensions is shown and the process is outlined. Comparisons with shot peening and polishing on normalized steel specimens for corrosion resistance and fatigue strength and quality of finish showed the process to be somewhat superior.

The Effects of High-Frequency Vibrations in Grinding. L. V. Colwell. (*Trans. Amer. Soc. Mech. Eng.*, 1956, **78**, May, 837–846). Vibrations artificially introduced between the workpiece and grinding wheel by an ultrasonic transducer improved the surface finish, reduced the ground surface temperature, and the incidence of thermal cracks and minimized the effects of hardness variations within the grinding wheel.—D. H.

CLEANING AND PICKLING

Using Blast Cleaning Techniques for Cleaning and Finishing. E. F. Anderson. (*Plating*, 1956, **43**, Jan., 82–86). The scope and application of dry and wet blast cleaning methods are discussed.—A. D. H.

How to Control Degreasing Costs. P. R. Hendrixson. (*Steel*, 1956, **138**, June 18, 184–185). Suggestions are made for determining the causes of inefficiency of degreasing tanks.

Modern Sheet and Plate Cleaning. (*Welding, Metal Fab.*, 1956, **24**, June, 212–213, 216). The use of the Vacu-Blast process for cleaning steel sheet and plate is described with illustrations.—U. E.

Glossary of Metal Cleaning and Finishing Terms. (*Iron Age*, 1956, **177**, June 28, 136–146).

Cleaning and Rust-proofing of Salt-bath Hardened Materials. C. Albrecht. (*Draht, German Ed.*, 1956, **7**, May, 186–188). Methods of removing salts from the surfaces and cleaning after quenching a similar treatment are described.

Metal Brightening. H. Silman. (*Metal Ind.*, 1956, **88**, Feb. 10, 105–108, 111). An account of electrolytic and chemical polishing processes as applied to stainless steel and other metals.

A Manufacturing Development: the Gyrofinishing Process for Polishing Metal Surfaces. G. R. Squibb and F. T. Hall. (*Gen. Motors Eng. J.*, 1956, **3**, May-June, 64–68). Using this process, metal parts whose surfaces require finishing are immersed—and held stationary—in a rotating drum containing an abrasive mixture. Details are given of several types of Gyrofinishing machine built, and the abrasive mixture finally

adopted. Even very irregular shaped parts have been given an overall uniform finish using this process.—E. A. C.

How to Finish Stainless Steel. R. E. Paret. (*Metalworking Prod.*, 1956, **100**, Feb. 10, 231–240). This report describes types of finish, explains for what application each is most suitable, and shows how to protect the finish during fabrication. It describes in detail how to produce various degrees of finish by abrasion—grinding, polishing, and buffing—and by electrochemical methods. Also discussed are etching, pickling, and various decorative finishing processes, such as electroplating, painting, and colouring.—M. A. K.

Production of Polished Surfaces. J. F. H. Wright. (*Commonwealth Eng.*, 1956, **43**, May, 315–317). Theories of surface finish are briefly considered and recent work carried out to study the nature of the polished surface is described.—B. G. B.

Pre-Finishing or Flat Polishing. R. W. Redmond. (*Plating*, 1956, **43**, Jan., 72–81). The application of methods of grinding steel in the form of sheets, strip or coil by a selected series of abrasive belts is discussed.—A. D. H.

Some Successful Applications of Electrolytic Polishing in Industry. R. Mondon. (*Sheet Metal Ind.*, 1955, **32**, Dec., 923–931, 934). The author reports some of his findings on the effect of electrolytic polishing on the properties of metal surfaces in connection with fatigue and corrosion. Examples of the application of the process to various production problems are given.—A. H. M.

Barrel Finishing—A Precision Tool. W. P. Nunn. (*Plating*, 1956, **43**, Jan., 60–63). The operation and applications of barrel finishing are described.—A. D. H.

Investigation of Barrel Finishing as a Means of Efficient Burr Removal. C. E. Kincaid. (*Gen. Motors Eng. J.*, 1956, **3**, Jan.-Feb., 34–39). The Barrel Finishing process has been found to be a faster method for removing burrs and also capable of giving a more uniform overall finish. The types of cleaning compound, and the different materials for burr removal are discussed, and the results achieved with four different applications of this process are described.—E. A. C.

Descaling Steel Sheet by Shot Blasting. W. Olson. (*Metal Progress*, 1956, **69**, June, 66–67). Shot blast descaling of hot rolled low carbon steel strip and sheet has been found to reduce the cost of scale removal by $4 per ton over pickling.

Good Rinsing for Good Plating. J. B. Kushner. (*Electroplating*, 1956, **9**, Feb., 44–47). Conditions for efficient washing during plating operations are laid down and the importance of the purity of the water supply and the influence of wetting agents and agitation are emphasized.—A. D. H.

Considerations on the Planning of an Automatic Plant. O. H. Lammert. (*Metalloberfläche*, 1956, **10**, Apr., 113–115). The necessary qualities for a fully-automatic electrolytic plant are discussed, its advantages are pointed out and an example is given of the solution of problems involved in automation of a pickling plant.—L. D. H.

The Mechanization of Electrolytic Operations. G. Elssner. (*Metalloberfläche*, 1956, **10**, Apr., 115–119). A general description is given of recent developments in the mechanization of electrolytic and phosphating plant, including equipment for pickling and electroplating wire.—L. D. H.

The Effect of Pickling Additives on Hydrogen Embrittlement. A. Keller and R. Keller. (*Draht, English Ed.*, 1956, April, 38, 40, 42, 44). A brief discussion of theory is followed by an account of tests on proprietary materials.

PROTECTIVE COATINGS

How Standardization Can Serve as a Guide for Corrosion Protection by Metallic Coatings. P. Morisset. (*Corrosion et Anticorrosion*, 1956, **4**, Jan., 22–35). Standardization of metallic coatings, accelerated corrosion tests, manufacture, terminology, products protected by coatings, and recommendations for use are discussed.—T. E. D.

Automatic Equipment for Electroplating Operations. K. Gebauer. (*Metalloberfläche*, 1956, **10**, Apr., 98–103). After reviewing the development of automatic plant in U.S.A. and Germany, the three main automatic systems are described. The mode of operation of the most important automatic components is illustrated by an example, and a description is given of individual units.—L. D. H.

Automatic Electroplating Equipment of the Firm of Dr. W. Kampschulte & Cie., Solingen. G. Geilert. (*Metalloberfläche*, 1956, **10**, Apr., 103–106). Operational details are given of a modern fully automatic electroplating plant.—L. D. H.

Automatic Electroplating Equipment of the Firm of Riedel & Co., Bielefeld. W. Pech. (*Metalloberfläche*, 1956, **10**, Apr., 106–110). A review is given of the development and present position of automation in the plant constructed by Riedel and Co.—L. D. H.

Production of Coatings on Steel by Chromium Diffusion. J. Saenz Insausti. (*Inst. Hierro Acero*, 1956, **9**, Jan.-Mar., 250–257). [In Spanish]. The gaseous chromizing process in use at the Instituto Nacional de Técnica Aeronáutica is described. The articles are packed in kaolin containing 30–50% Cr and 0·2–0·4% NH_4I, in a closed retort which is sealed with a 31% borax–33%litharge–36% sand mixture. This seal remains porous up to 750° C and allows the expulsion of air from the box; above this temperature it vitrifies. The influence of time, temperature, and alloying elements upon the thickness and structure of the coating are described briefly. Various chromized articles are illustrated. (10 references).—P. S.

The Use of Cast, Rolled, and Electrolytic Nickel Anodes in Various Nickel Baths. H. Offermanns, H. v. Feld, S. Kalbitzer, and W. Schröder. (*Metalloberfläche*, 1956, **10**, Jan., 22–23).

A Radioisotope Study of the Nickel Dip. J. C. Richmond, H. B. Kirkpatrick, and W. N. Harrison. (*J. Amer. Ceram. Soc.*, 1956, **39**, Feb., 39–46). A study is reported, of the deposition of nickel during nickel dipping of enamelling steel and of the effect of this nickel deposit on the reduction of cobalt ions to cobalt during enamel firing. The deposition of both metals was found to be affected by the type of cleaning given to the steel, and by mechanical deformation of the metal surface. The nickel remained as metal at the interface during firing of the enamel. The presence of the nickel deposit had little or no effect on the deposition of cobalt at the interface during firing.—D. L. C. P.

Continuous Hot Dipped Galvanizing. N. E. Cook and M. D. Ayers. (*Iron Steel Eng.*, 1956, **33**, April, 53–57). The authors describe the Wheeling Steel Galvanizing process in which cold reduced, box annealed and temper rolled coils are charged to the galvanizing line. There is no annealing of the strip in the line. The advantages of the process are claimed to be flexibility and the control of the zinc coating.

The Use of Metallizing with Zinc in France. (*Usine Nouvelle*, monthly edition, 1956, Mar., 53–57). Extremely thorough descaling must be carried out before metallizing which must follow within 3 hours. The zinc layer can then be sprayed with rain or sea water, giving an outer protective layer of bicarbonate or oxychloride. Control and applications are outlined.—T. E. D.

Here's Some Design Tips to Consider when Parts Call for Hot Dip Galvanizing. H. Slack. (*Western Metals*, 1956, **14**, Mar. 56–57). A few general topics are noted.

Black Stains in Dry Galvanizing. H. Bablik, F. Götzl, and E. Nell. (*Metalloberfläche*, 1956, **10**, Feb., 33–34). To the extent that black stains on the galvanized work are due to the action of the flux, their occurrence is attributed to the presence of aluminium in the flux, particularly if zinc ash itself contains aluminium. A high aluminium content in the zinc bath itself can also cause the same trouble.—L. D. H.

Recovery of Zinc Contained in Zinc–Iron Crusts from Galvanizing Baths by the Process Used at the Institute of Technological Research, São Paulo. T. D. de Souza Santos. (*Bol. Assoc. Brasil. Met.*, 1956, **12**, Jan., 15–26). [In Portuguese]. The results of pilot experiments are described. The crusts are fragmented and the zinc is sublimed *in vacuo*. (0·5 mm Hg) at 750° C in chromium–nickel cast iron retorts. The process is both efficient and economic, 85 to 91% of the zinc; containing 0·14% lead, 0·1% iron max., is recovered.

New Developments in the Manufacture of Tinplate. B. Keysselitz. (*Stahl u. Eisen*, 1956, **76**, Mar. 8, 267–272). The considerable increase in world tinplate production was made possible by the evolution of the continuous strip rolling and galvanic tinning techniques, the latter permitting much thinner coatings than hot tin plating. Hot tinning plant for plate has also been much improved in construction. The German type of hot tinning plant for strip is briefly touched upon by the author, and British experiments with entirely new processes are referred to. A review of the history, and advantages and disadvantages, of the galvanic technique is given, and the direction of future development is discussed.—A. C.

Chemical After-Treatment of Tinplate. E. S. Hedges. (*Stahl u. Eisen*, 1956, **76**, Mar. 8, 277–280). Hot dipped or

galvanic coats are porous, and rusting is consequently possible. This can be guarded against by the application of lacquer, but it is also possible by means of a simple chemical after-treatment to obtain an invisible protective film of oxide on the tinplate. Dipping for 3–5 hours at 90–95° C in a solution of sodium hydroxide and sodium chromate is adequate. An investigation of the effectiveness of the treatment is described.—A. C.

New Uses for Tinned Cast Iron. (*Tin*, 1956, June, 120). A note on the direct chloride process of the Tin Research Institute.

Depolarization by Mercaptoacetic (Thioglycollic) Acid during Electrodeposition of Copper. A. J. Sukava and C. A. Winkler. (*Canad. J. Chem.*, 1956, **34,** 2, Feb., 128–132). A study was made of the effect of various additions, and the results are discussed.—E. E. W.

Hot-Dip Aluminized Steel, Its Preparation, Properties, and Uses. M. L. Hughes. (*Sheet Metal Ind.*, 1956, **33,** Feb., 87–96, discussion 97–98). A review of manufacture with an account of structure, resistance to deformation and resistance to heat with notes on other properties. Uses are very briefly considered.

Electrolytic Protection of Steel by Deposits of Cadmium–Titanium Alloy. R. Michel. (*Corrosion et Anticorrosion*, 1956, **4,** Jan., 36–39). Deposits of cadmium–titanium are definitely better than those of the already known zinc–titanium alloy. The deposits contain only a very small proportion of titanium, but provide better protection than high-quality hard chrome. Brief details of the method of depositing are given, and testing of anti-corrosive properties is outlined.

Recent Developments in Metal Spraying. (*Corrosion Prevention and Control*, 1956, **3,** May, 38–42). The recent developments in the field of sprayed metal coatings, with particular reference to the coating of steel with aluminium and zinc, are reviewed. The properties, limitations and applications of such metal coatings are outlined and reference is made to the 'Spraywelding' process by which hard deposits of nickel–chromium–boron alloys can be applied. The problems that arise due to the characteristic porosity of sprayed metal coatings are discussed and the choice of fuel gas is dealt with very briefly. The article concludes with a summary of recent specifications. (14 references).—L. E. W.

Properties of Flame-sprayed Zinc Layers. E. Gebhardt and H. D. Seghezzi. (*Z.Vd.I.*, 1956, **98,** Jan. 11, 41–45). The authors investigated the mechanical properties and electrical conductivity of sprayed zinc layers as a function of spray-gun design, type of flame, and thickness and surface roughness of base. Both zinc wire and powder sprayed with neutral and oxygen-rich flames, produced similar results. The adhesion depended significantly on the surface roughness of the base.—J. G. W.

The Metal Spraying of Zinc and Aluminium. G. H. Jenner. (*Steam Eng.*, 1956, **25,** Jan., 140–142). The three methods of applying metal by spraying, namely wire, powder and molten metal, are outlined. A suitable surface for metallizing is obtained by blasting with chilled iron grit. B.S.S. No. 2569/1955, Parts I and II is quoted.—T. E. D.

Wear Protection of Mild Steel by Phosphating. J. W. Midgley. (*J. Iron Steel Inst.*, 1957, **185,** Feb., 215–224). [This issue].

Phosphating. L. A. Rubio Felipe. (*Inst. Hierro Acero*, 1956, **9,** Jan., 92–99. *Special Number*). [In Spanish]. The factors which influence the technique of phosphating, the properties of the coatings, and the phosphating processes are discussed. The author has studied baths containing manganese or zinc phosphates and has found that the former gives better protection especially after washing with 0·5% chromic acid solution. When this bath contains an accelerator (0·75% sodium nitrate) the chemical control of acidity is not rigorous and so is more adaptable to mass production methods. The manganese bath is also recommended for anti-friction requirements; the zinc bath for assisting cold working.—P. S.

Protecting Steel From Wear by Phosphating. J. W. Midgley. (*Engineering*, 1956, **181,** April 13, 196). The wear characteristics of phosphated mild steel bearings are discussed briefly. The advantages of the process are ascribed to the particular modifications of the surface profile which result from the phosphating. (6 references).—M. D. J. B.

Phosphating Processes for Marine Anti-Corrosion Purposes. (*Corrosion Prevention and Control*, 1956, **3,** June, 51–52). A brief description is given of the successful application of the cold brush-on type of phosphating process to the s.s. *Clan Sutherland* (belonging to Cayzer, Irvine & Co. Ltd.) and eleven other ships. The *Clan Sutherland* was treated below the water line with Foscote R.S. and the phosphate coating produced was sealed with one coat of Impervo yellow metal primer followed by Impervo red primer. A finishing coat of anti-corrosive composition and a tropical anti-fouling paint were also applied.—L. E. W.

Corrosion Resistant Linings for Ships' Oil Tanks. (*Engineer*, 1956, **201,** April 6, 304). This article describes a synthetic resin known as Prodor-Glas for application as a corrosion-resistant coating to metal tanks and other equipment.

Temporary Protective Coatings: 1—Metallic Naphthenate Solutions. E. Strong. (*Product Finishing*, 1956, **9,** Feb., 65–83). Desirable properties sought in coatings to prevent corrosion and scratching in service and transit are considered. The applications, and characteristics of solutions of copper zinc, and nickel naphthenates in white spirit are described.

Modern Electroplating Methods. E. Roth. (*Metall*, 1956, **10,** June, 505–513). The most important electroplating methods currently in use are described and their merits discussed. Included are alloy coatings and the development of automatic methods for mass production.—J. G. W.

Base Metal and Coating. J. Fischer. (*Metall*, 1956, **10,** June, 499–503). Causes of poor adhesion between coatings and base metals such as inclusions, surface contamination, etc., are discussed. Methods of surface preparation prior to coating are outlined.—J. G. W.

Chrom Alloy Surfacing. E. Magder. (*Canad. Metals*, 1956, **19,** May, 58–60). The properties of chromalloyed surfaces and the advantages of the process are briefly described.—B. G. B.

Proposed Substitutes for Nickel Plating. A. K. Graham. (*Plating*, 1956, **43,** Feb., 218–220). The replies to a questionnaire sent to 24 companies and individuals concerning their experiences with substitutes for nickel/chromium plating over ferrous metals are presented. No material with the possible exception of copper–tin coatings are considered to equal Ni/Cr for outdoor applications.—A. D. H.

Is Tin–Nickel the New Plating Finish You Need ? R. T. Gore, F. A. Lowenheim. (*Iron Age*, 1956, **177,** May 31, 59–61). The process and properties of a tin–nickel plating which is coming into commercial use are described. The alloy contains 65% Sn, 35% Ni, and plates directly on to most basis metals. The solution has a high deposition rate and good throwing power and is easy to control. The coating has good decorative and protective properties.—D. L. C. P.

Wire Spirals Through Plating Bath. (*Steel*, 1956, **138,** June 11, 129–132). The improved "Kenmore" process at National-Standard Co., Mich., produces "Ferniclon," a nickel coated steel wire; the process, product and applications are described. The coiled wire is spiralled continuously through the cleaning and plating baths. It is then drawn by conventional methods to finished size.—D. L. C. P.

A Survey of Literature on Hot Dip Galvanizing, 1950–1955. J. J. Sebisty. (*Canada Dep. Mines and Techn. Surveys, Mines Branch Res. Rep. No. PM* 202, 1956, April 23, pp. 60). A review with 109 references.

Continuous Galvanizing Plant Installed at Warrington. (*Indust. Gas*, 1956, **19,** May, 270–276). A new continuous annealing and galvanizing plant for the treatment of mild and high carbon steel, installed at the works of The Firth Co. Ltd. in collaboration with The Incandescent Heat Co. Ltd. is described with particular reference to the gas heated lead bath and galvanizing bath.—D. H.

Diagram for the Calculation of Zinc Coatings on Round Iron or Steel Wire. W. Mallach. (*Draht, German Ed.*, 1956, **7,** June, 214). A family of lines on a log.–log. scale are given for the calculation of zinc per ton or per m² of wire.

The Modern Galvanized Sheet and its Uses. F. H. Smith. (*Sheet Metal Ind.*, 1955, **32,** Oct., 735–740, 744). This article discusses galvanized sheet produced by the modern continuous process, gives details of its fabrication into finished parts and illustrates its adaptability by reference to its high-grade finish and workability.—A. H. M.

Remarks on the Attack of Zinc on the System Iron–Iron Carbide. W. Kroos. (*Metalloberfläche*, 1956, **10,** June, 187–188). The report describes the metallurgical conditions which lead to the attack of zinc on ferrite, but particularly on carbide and pearlite. The influence of higher temperatures on the formation of cavities is discussed, and the effect of aluminium

and the higher stability of graphite and temper carbon compared with carbide are indicated.—L. D. H.

The Attack by Iron-saturated Zinc Melts on Silicon- and Manganese-containing Iron. H.-J. Wiester and D. Horstmann. (*Forschungsberichte des Wirtschafts- und Verkehrsministeriums, Nordrhein-Westfalen, No.* 291, 1956, pp. 40). The relationships of loss of iron to temperature and composition up to 495° are shown to be complex, with a parabolic region in each case followed by a break.

A Rust-Resistance Test for Tinplate. S. C. Britton and D. G. Michael. (*Sheet Metal Ind.*, 1955, **32**, Aug., 576–580). Limitations of existing methods of porosity estimation are discussed. A new method is described based on the fact that tin and iron differ considerably in their resistance to corrosion by atmospheres containing sulphur dioxide. The recommended procedure is capable of indicating, within 24 hours, the liability of samples to rusting by condensed atmospheric moisture.

Try Flame-Plated Coatings Where Service is Severe. M. A. Teter. (*Mat. Methods*, 1956, **43**, Feb., 100–102). Tungsten carbide deposition is advocated with examples of its use.

Further Development of Metal Spraying Technique. H. Reininger. (*Metalloberfläche*, 1956, **10**, June, 181–185). This is a review of the literature dealing with recent developments in metal spraying equipment and techniques. A detailed description is given of the Metagon-Elektro pistol; the output of 2 mm steel wire is given as 17·5–20 kg/h. The after-treatment of coatings sprayed on steel and other materials is discussed.—L. D. H.

The Prevention by Metal Spraying of Steel Craft Corrosion. (*Corrosion Prevention and Control*, 1956, **3**, June, 54). Various examples are given of the successful application of Schori sprayed zinc coatings to ocean-going liners, and vessels of the R.N. and R.A.F. The Schori equipment is also used to spray the synthetic rubber Thiokol.—L. E. W.

Flame Plating with Tungsten Carbide. R. H. Eshelman. (*Engineers' Digest*, 1956, **17**, March, 99–100). Developed by Linde Air Products Co., U.S.A. and first reported in 1952 a commercially practicable process, based on accumulated experience, has been evolved for depositing carbide coatings by blasting tungsten carbide particles through a special gun, using explosive gases as a carrier. This method of bonding, known as flame plating, retains the properties of both the base material and the coating.—U. E.

Oxide Films on Stainless Steels. T. N. Rhodin. (*Corrosion*, 1956, **12**, Mar., 123t–135t). Three types of oxide film on stainless steels are differentiated by film thickness, structure, and composition and the influence of the film on resistance to corrosion. Special microanalytical techniques were used to study the composition of oxide films removed from stainless steels. Structural and other properties of passive films were evaluated and related to the alloy composition and surface treatments. Corrosion resistance is dependent on the composition of the film. Film composition after immersion in acids is related to film composition before immersion. Their iron and silicon contents reflected most clearly the corrosion properties of the films.—J. F. S.

Protective Coal Tar Coatings in Steel Plants. W. F. Fair, Jun. and H. J. Cibula. (*Iron Steel Eng.*, 1956, **33**, Feb., 106–116). The authors give information which will aid in selecting the most appropriate type of coal tar coating for the surface to be protected, the corrosive environment to be encountered, the accessibility of the structure needing insulation, and the expected service life of the protective coating system selected. (11 references).—M. D. J. B.

The Trend Towards Plastic Coatings in Anticorrosion. L. Rémy. (*Corrosion et Anticorrosion*, 1956, **4**, June, 217–221). Bituminous and synthetic resin coatings are discussed.—T. E. D.

Applications of Plastics in Marine Cathode Protection Systems. H. S. Preiser and M. Stander. (*J. Amer. Soc. Naval Eng.*, 1956, **68**, Aug., 581–590).

Recent Developments in the Technology of Porcelain Enamelling on Steel in the U.S.A. E. M. Hommel. (*Sheet Metal Ind.*, 1955, **32**, July, 531–536). The article deals with the "Eckel-Romnie Process," the "Ferro-Republic Direct Application Process," and the application of titania-opacified enamels direct to titanium steel. Coloured and luminescent enamels are discussed together with methods of spraying and grinding.—A. H. M.

Flow-Coat Finishing of Automobile Chassis Frames. C. R. Herter. (*Indust. Heating*, 1956, **23**, Mar., 568–578). The lay-out and operation of a continuous system for cleaning, painting, and drying welded chassis frames is described.—A. D. H.

Analytical Methods for Waste-Water Control in Electrolytic Operations. F. v. Ammon. (*Metalloberfläche*, 1956, **10**, June, 161–164). Rapid qualitative and quantitative methods are described for the detection and determination of cyanide, copper, and chromium in the waste water from electroplating plants.—L. D. H.

POWDER METALLURGY

Reduction Structures of Iron Powder. J. O. Edström. (*Jernkontorets Ann.*, 1956, **140**, 2, 116–129). [In Swedish.] Experiments have confirmed that Fe_2O_3 concentrate is completely reduced by CO and H_2 at roughly 1000° C, whilst Fe_3O_4 too can be completely reduced at this temperature by CO or a gas containing CO. Both can be reduced at 500–600° C by pure H_2. Micrographs are shown of iron powder produced from these concentrates under various conditions. It was observed that the use of H_2 gave denser structures than if pure CO were employed. Also, by selecting a suitable degree of oxidation, reduction temperature, and gas composition it is possible to adjust the amount and appearance of the pores in iron powder directly reduced by gas from concentrate.

General Solutions of the Equations of Elasticity and Consolidation for a Porous Material. M. A. Biot. (*J. Appl. Mech.*, 1956, **23**, Mar., 91–96).—D. H.

Process Control for Powdered Metals. (*Steel*, 1956, **138**, May 14, 118–121). The control of materials, parts, and processes during manufacture of powdered metal ware is considered.—D. L. C. P.

Sintered Components. (*Automobile Eng.*, 1956, **46**, July, 268–275). A comprehensive account of the use of powder metallurgy in the production of small parts for the automobile industry in Britain is presented. Twelve advantages and four drawbacks of the process are enumerated and discussed, and surface treatment, sinter brazing, source of metal powders, furnace and furnace atmospheres, and sizing and inspection are all reviewed.

The Rolling of Strip from Metal Powders. P. E. Evans and G. C. Smith. (*Sheet Metal Ind.*, 1955, **32**, Aug., 589–592). The authors begin with a brief account of Bessemer's technique of rolling brass turnings and a historical survey. An account is then given of investigations carried out on a standard two-high mill. Size of product and factors governing strip thickness are discussed. A procedure is given of sintering iron strip by heavy currents and the subsequent cycle of cold rolling and annealing. A strip having a tensile stress of 31 kg/mm² and 25% elongation can thus be obtained. The authors finally discuss the potentialities of the method.—A. H. M.

How Metallography Helps Sintering. R. B. Thomson, A. B. Wendt. (*Steel*, 1956, **138**, May 21, 110–111). The application of metallography to solving a problem of deterioration in quality of copper-impregnated, sintered iron alloy gears is described. The solution was to avoid cementite formation and obtain an essentially pearlitic structure.—D. L. C. P.

PROPERTIES AND TESTS

Study of Control Phenomena by Means of a Time Step Transfer Function. V. Ferner. (*Technik*, 1956, **11**, Apr., 301–308). The author defines this function as the sum of two step functions of equal magnitude, opposite sign, and displaced in time by the effective deadbeat interval of the system. The uses of this function in the performance analysis of servo-systems is argued.—J. G. W.

The Value of Continuous Measurements for Statistical Quality Control. W. Masing. (*Draht, German Ed.*, 1956, **7**, Mar., 87–91). Graphical, numerical, and machine methods are given with an example.

A Thermoelectric Method of Sorting Steel. S. Gorczyca and J. Maydell. (*Hutnik*, 1955, **22**, (10), 362–368). A heated and an unheated contact separated by a fixed distance and connected to a galvanometer are placed on the steel and the e.m.f. is measured at standard temperature differences. The method offers several advantages over spectroscopic sorting, notably that the test can be made *in situ*, no standard specimens are necessary, and there is no need for expensive apparatus or dark-room facilities. The method can be used by calibrating the apparatus for different steels, or by using standards, and has been applied to the sorting of Cr–Ni, case-hardening, spring, tool, high-speed, and stainless steels.

Principles of Electrical Instruments for the Measurement and Inspection of Surfaces. F. Seeboth. (*Z.V.d.I.*, 1956, **98**, June 1, 869–874). Working principles of electrical instruments for the measurement of surface roughness and specifications of three German and the Philips instruments are quoted.—J. G. W.

Some Observations on Shooting Bolts into Metals. K.-A. Ebert, W. Hofmann, and G. Seitz. (*Z. Metallkunde*, 1956, **47**, Jan., 24–28). Steel bolts were shot into aluminium, copper, and steel, and the force measured which was required to withdraw them. This force measured 780–1700, 250–1570, and 0–2100 Kp. respectively. Contrary to expectation, it was found that the tip of the bolt was raised to an austenizing temperature in penetrating the base metal, and subsequently became re-hardened. It was found that the bolts were partially welded to the base material.—L. D. H.

Apparatus for Determining the Specific Gravity of Powdered Materials. S. S. Fedorov. (*Zavodskaya Laboratoriya*, 1955, **21**, (10), 1253–1254). [In Russian]. A brief account is given of an apparatus for determining the volume of powdered materials for calculation of specific gravity. Krivoi-Rog iron ore is one of the materials dealt with.—S. K.

A New Approach to the Properties of Steels in Engineering. H. Muir. (*J. Inst. Eng. Australia*, 1956, **28**, June, 161–168). A method of measurement of elastic limit is described. This is of high precision and is correlated with various conventional tests and with properties of hardened steel. Possible correlation with temper brittleness was also observed. Applications in engineering are suggested.

A Simple Picture of Metal Structure. E. Schwarz-Bergkampf. (*Radex-Rundschau*, 1955, Dec., 659–663). Bonding electron pairs and conductivity electrons are considered in relation to bonding strength and plasticity. Density and alloy formation and ferromagnetism are touched upon and the catalytic effects of noble metals.

Two-center Integrals for Body-centered Iron Using Atomic Functions with Exchange. M. Suffczyński. (*Acta Phys. Polonica*, 1956, **15**, 111–115).

Why Specify Ductility? W. K. Bock. (*Machine Design*, 1956, **28**, Jan. 12, 133–136). The author analyses the conditions which may promote fracture of alloys in service; fatigue, stress raisers, impact loading, loading at elevated or low temperature. It is claimed that there is no relationship between the ductility of a metal in the static tension test and the probability of a failure under service conditions. There are, however, still valid reasons for specifying ductility.—M. A. K.

Requirements for the Endurance Testing of Cylindrical Helical Springs. S. Gross. (*Draht, German Ed.*, 1956, **7**, Apr., 116–119). A mathematical treatment is given.

Measurement of the Damping of Metal Bar Specimens in Mechanical Resonance. H. Pursey and E. C. Pyatt. (*J. Sci. Instruments*, 1956, **33**, Mar., 123–124). Additional circuits have been added to an apparatus for measuring natural resonance frequencies of metal bar specimens (c.f. *Ibid.*, 1954, **31**, 248) enabling the Q-values of the specimen to be obtained. Two methods are used, depending on the level of the Q-value.

Apparatus for Determining the Modulus of Elasticity at Various Temperatures. E. M. Pavlov. (*Zavodskaya Laboratoriya*, 1955, **21**, (10), 1241–1242). [In Russian]. A static method for the determination of the temperature coefficient of shear modulus is briefly described. The test-piece is in the form of wire with diameter 0·2–0·5 mm and the temperature range − 60° C to + 80–150° C.—S. K.

On the Decrease of Young's Modulus of an Elastic Body with Contact Surface. S. Suzuki. (*J. Mech. Lab.*, 1956, **10**, Jan., 1–3). The decrease of Young's modulus with increasing contact load is estimated theoretically for a given roughness of the contact surface, and the results are compared with experiments.—J. G. W.

On the Relations Between Various Laboratory Fracture Tests. E. M. Lape and J. D. Lubahn. (*Trans. Amer. Soc. Mech. Eng.*, 1956, **78**, May, 823–835). Some correlation between different types of mechanical tests including notched and unnotched tensile, bend, disc-bursting, and Charpy impact tests, was attempted by subjecting a steel of composition C 0·12%, Mn 0·48%, Cr 5·87%, Mo 0·95%, Ti 0·37%, B 0·03% to all tests in various conditions of heat-treatment. General correlation was obtained only between unnotched bend and tensile tests.—D. H.

Influence of Loading Rate on the Stress–Strain Diagram Obtained from Tensile Tests. F. Fischer. (*Metall*, 1956, **10**, May, 419–423). Investigations of mild steels confirm the influence of the rate of loading on the stress–strain curve close to the yield point. Attempts are made to account for this in terms of metal physics.—J. G. W.

A Modified Incremental Strain Law for Work-Hardening Materials. W. H. Warner and G. H. Handelman. (*Quart. J. Mech. Appl. Math.*, 1956, **9**, Sept., 279–293). A mathematical account of a generalized incremental strain law is presented.

Study of Properties of Shell-cast Gray Iron Tensile Test Bar. T. Tanaka and T. Watanabe. (*J. Mech. Lab.*, 1956, **10**, Mar., 61–66). The cooling rates and mechanical properties of grey iron tensile test bars were compared, when cast into shell moulds and green sand moulds by the J.I.S. process. Shell castings with and without back-ups solidified faster than sand castings and had higher tensile strength.—J. G. W.

Device for Measuring Contraction in the Notch. Yu. I. Likhachev. (*Zavodskaya Laboratoriya*, 1955, **21**, (10), 1244–1245). [In Russian]. An indicating device is briefly described with which the decrease in the diameter at the notch of a peripherally-notched cylindrical tensile test-piece can be determined without having to remove the load.—S. K.

Relative Reduction in Area of Thin Sheet Metal Test-Pieces. P. S. Sakharov. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 981–982). [In Russian]. From an analysis of testing methods and results it is concluded that for sheet metal the relative reduction in area should be calculated from the true cross-sectional area at the fracture of the test piece.—S. K.

Effect of Temperature on Delayed Yielding of Mild Steel for Short Loading Duration. J. M. Krafft. (*Trans. Amer. Soc. Metals*, 1956, **48**, 249–264). A description is given of a bar loading technique developed for applying uniform compressive stress for a duration of 100 microseconds and allowing measurement of time delay before plastic yielding within this duration. The results are given for tests on mild steel at five temperatures between + 100° and − 196° C.—E. E. W.

The Mechanism of Plastic Deformation. W. T. Read, jun. (*Bell Lab. Record*, 1956, **34**, Apr., 133–136). Models are described and illustrated and the Frank–Read mechanism is discussed.

Combined Stress Tests in Plasticity. A. Phillips, and L. Kaechez. (*J. Appl. Mech.*, 1956, **23**, March, 43–48). Some basic assumptions in the incremental theory of plasticity have been tested and proved correct. Thin walled tubes were subjected to (*a*) combined tension and torsion with variable stress ratios; (*b*) uni-axial tension into the plastic region and the state of uni-axial tension rotated with the magnitude of the principal stresses remaining constant.

Plasticity Equations and Their Application to Working of Metals in the Work Hardening Range. E. G. Thomsen. (*Trans Amer. Soc. Mech. Eng.*, 1956, **78**, Feb., 407–412). Plasticity equations applicable to forming operations of metals in the work hardening range are presented and examined and three solutions for extruding aluminium in a frictionless apparatus at room temperature compared.—D. H.

The Pattern of Plastic Deformation in a Deeply Notched Bar With Semicircular Roots. L. Garr, E. H. Lee, and A. J. Wang. (*J. Appl. Mech.*, 1956, **23**, March, 56–58). The plastic deformation in a notched bar with deep semi-circular roots in tension in plain strain is determined theoretically.

Effect of Small Deformations on the Yield-Point of Cold Rolled Deep Drawing Steel Strip Having a Low Carbon Content. F. Fischer, M. Nacken, and V. Seul. (*Stahl u. Eisen*, 1956, **76**, Jan. 26, 82–93). Planned investigations were carried out on the effects of light finishing passes on the yield point, tensile strength, elongation, cupping and hardness of deep drawing strip with low carbon content. The experimental materials and method are described, and test results given. The effects of varying storage time, heat treatment and the finishing pass are discussed. The theoretical significance of the behaviour of the yield-point after light finishing passes is examined.

Stress Concentration Caused by Multiple Punches and Cracks. M. Sadowsky. (*J. Appl. Mech.*, 1956, **23**, March, 80–84). The paper contains (*a*) a general theory of stress distribution under several punches in simultaneous action and of stress concentration caused by cracks; (*b*) a complete evaluation for the case of two punches or two cracks.—D. H.

Novel Methods of Determining Plastic Deformation Coefficients. Z. Wusatowski. (*Neue Hütte*, 1956, **1**, Mar., 275–279). Cold rolling tests on lead and aluminium samples have shown that the usual practice of expressing plastic deformation in terms of relative decreases in height is mistaken, and applies

only to minor deformation up to 5%. Correct determinations of major plastic deformation for practical purposes must be based on elongation, compression, and spreading indices, taking actual elongation into consideration.

Internal Friction in Metals. G. Löschner. (*Technik.*, 1956, **11**, Apr., 289–300). This is a survey of the subject. (183 references).

Internal Friction, a New Physical Property for the Study of Metals. T. Federighi. (*Alluminio*, 1956, **25**, May, 225–230). Theory and methods of measurement are given with notes on its metallurgical significance.

Internal Friction in α-Iron Due to Interstitial Solutes. R. Rawlings. (*Acta Met.*, 1956, **4**, Mar., 213). [In English]. A letter in which expressions for the anelasticity of an aggregate of randomly oriented crystals and of a wire with a <110> texture proposed by G. Lagerberg and Åke Joseffson. (*Acta Met.*, 1955, **3**, 236), are worked out and compared with results of internal friction experiments.—A. D. H.

Internal Friction Measurements on Tempered Martensite. P. Stark, B. L. Averbach, and M. Cohen. (*Acta Met.*, 1956, **4**, Jan., 91). A letter, in which the results of internal friction experiments on quenched and tempered 0·78% C steel are briefly reported and discussed. The carbon peak is not detected until martensite has been tempered for 1 hour at 485° C and has only a low intensity.—A. D. H.

The Structures and Energies of Grain Boundaries in Metals. F. Erdmann-Jesnitzer. (*Hutnické List*, 1956, **11**, (4), 207–213; (5), 290–299). [In Czech]. A critical survey is made of recent developments in the understanding of the nature of grain boundaries, including dislocation models of small-angle boundaries, damping effects due to boundary glide, and the role of surface tension in grain-growth in mono- and polyphase systems. Some of the author's own researches now in progress are mentioned.—P. F.

Some Considerations on the Tensile and Transverse Strength Strength Testing of Shell Mould and Core Sands. P. J. Ahearn, F. Quigley, J. I. Bluhm, and J. F. Wallace. (*Amer. Found. Soc. Preprint*, 1956, No. 168). Photoelastic analysis revealed that the standard tensile test briquet used for baked core and shell moulding sands is subjected to stress concentrations at the contact points of the grips and to a non-uniform stress distribution across the centre section. Results are presented to show that the use of steel clips at the location of the grips slightly improves the strength of dumped shell mould specimens but does not affect the tensile test results from rammed resin- or oil-bonded sand briquets. A new design of tensile test briquet is described which gives higher strengths with all the sands, and better reproducibility for rammed resin- and oil-bonded sands. The use of 5 in. radius loading supports in the standard transverse test slightly improved the strength and uniformity of the results for dumped shell mould sand, but had a negligible effect on the data from standard baked core transverse tests.—B. C. W.

Mechanical Properties of Medium-Carbon Boron Steels J. R. Kattus and C. L. Dotson. (*Metal Progress*, 1956, **69**, Apr., 68–72). The tensile fatigue, impact and notched-tensile properties of tempered medium-carbon boron steels are equivalent to those of other low alloy steels tempered to the same hardness level.—B. G. B.

500 Ton Universal Vertical Testing Machine. (*Engineer*, 1956, **202**, Aug. 3, 161–162). A description of the installation at the Naval Construction Research Establishment.

Tension Testing Apparatus for the Temperature Range of − 320° F to − 452° F. E. T. Wessel. (*Amer. Soc. Test. Mat. Bull.*, 1956, Jan., No. 211, 40–46). A relatively simple apparatus, economical to operate and capable of testing to a 20,000 lb load is described. Liquid helium is used as the refrigerant.—B. G. B.

A Study of Shrinkage during Tensile Testing of Tubes. H. de Leiris. (*Rev. Mét.*, 1956, **53**, Jan. 37–47). The use of hollow test pieces is shown to require a correction for diameter to make elongation as measured independent of relative thickness.

Influence of Microstructure of Steel on the Coefficient of Cold Hardening n Determined during Tensile Tests in the Range $E_{0·01} - E_{0·2}$. Possible Relations between this Coefficient and the Phenomena of Adaptation. G. Delbart and F. Maratray. (*Compt. Rend.*, 1956, **242**, June 4, 2718–2720). Martensite, bainite, and mixed structures are investigated and the effects of quenching and tempering are considered.

The Influence of Hydrogen on the Yield Point in Iron. H. C. Rogers. (*Acta Met.*, 1956, **4**, Mar., 114–117). [In English]. After electrolytic charging with hydrogen, Armco iron no longer exhibits a yield point at room temperature or below. The yield point reappears at − 12° C. The effect is discussed with reference to dislocation theory.—A. D. H.

The Influence of Hydrogen on the Yield Point of Mild Steel. H. G. Vaughan and M. E. de Morton. (*Acta Met.*, 1956, **4**, Mar., 224–225). [In English]. The effect of hydrogen in removing the yield point from mild steel is confirmed. Hydrogen is also shown to cause strain ageing in a non-strain ageing steel. The effects are discussed briefly.—A. D. H.

Abnormal Fractures. L. Hurtado Acera. (*Inst. Hierro Acero*, 1956, **9**, Jan., 59–62. *Special Number*). [In Spanish]. An illustrated account is given of abnormal fractures produced in tensile test-pieces of stainless steel (0·15% C, 10% Cr, 1·48% Ni) tempered after oil-quenching from 950° C. These complex, partly longitudinal, fractures occurred in specimens tempered to the intermediate range of tensile strengths (88 to 107 kg/mm²), but were not accompanied by abnormal mechanical properties. It is suggested that the low shear strength/tensile strength ratio of this class of steel may provide an explanation of this abnormal type of fracture. The author suggests that a standard system of classification of all types of fracture should be adopted.—P. S.

A Bend-Test Method of Determining the Stress Required to Cause Creep in Tension. J. B. Wachtman and L. H. Maxwell. (*Amer. Soc. Test. Mat. Bull.*, 1956, Jan., No. 211, 38–39). A method is described which permits the use of bending tests to determine this stress when conventional techniques cannot be used.—B. G. B.

Fracture Behaviour in the North Slow-Bend Test. W. J. Murphy, R. D. Stout. (*Welding J.*, 1956, **35**, April, 169s–180s). The Kinzel-type longitudinal-bead weld test was used. A detailed study was made of the effect of weld metal, heat affected zone and unaffected base plate in the initiation and propagation of the crack leading to brittle fracture. The microstructures were examined and the examination and analysis of fracture patterns on Kinzel test specimens was found to be a valuable method of determination of the influence of weld metal, heat-affected zone and base metal on the welded transition temperature.—U. E.

Inequality Relations Between Torsional and Flexural Rigidity. J. Barta. (*Acta. Techn.*, 1956, 14, (3–4), 477–479). [In English].—P. F.

A Small and Inexpensive Device for Sustained Loading Testing. R. G. Raring and J. A. Rinebolt. (*Amer. Soc. Test. Mat. Bull.*, 1956, Apr., No. 213, 74–76). The apparatus is based on the elastic proving rings used for calibration of universal testing machines. The specimen is compressed inside a ring until the diameter of the ring corresponds to the desired load. An accuracy of ± 1% can be obtained.

Impact Ductility and Brittle Fracture. J. Götzlinger. (*Tek. Tidskrift*, 1956, **86**, Apr. 10, 335–339). [In Swedish]. After pointing out that the impact ductility of a material does not provide any measure of its strength and thus cannot be taken as a parameter when designing steel structures, especially since the notch sensitivity test results vary so much that no reliable conclusions can be drawn regarding the risk of brittle fracture, the author reviews factors governing notch sensitivity, tendencies towards ageing, and the effects of dynamic loads. An evaluation of past cases of brittle fracture is suggested.—G. G. K.

Low Temperature Impact Tests and the Determination of the Transition Range of Steels. F. Cacho Falco and J. Barrenechea Aberasturi. (*Inst. Hierro Acero*, 1956, **9**, Jan.-Mar., 306–314). [In Spanish]. No clear relationship was found between transition temperature and the Mn/C ratio in a series of fifteen normalized plain-carbon steels of different manufacture. The results are presented in statistical form.—P. S.

Classification of Weldable Steels by the Resilience Transition Temperature. R. Borione. (*Centre Doc. Sidér., Circ. Inform. Techn.*, 1956, **13**, No. 4, 765–783). After outlining the Charpy **V**-notch and keyhole tests, the relationships between the **V**-notch and keyhole transition temperatures are given, and the dependence of length of service on transition temperature is mentioned. Results of the two tests are shown graphically and are analysed. The influence of metallurgical factors on keyhole transition temperature is examined experimentally, using several steels. Discussion.—T. E. D.

Hot Tearing Characteristics of Acid and Basic Steel Castings Determined by High Temperature Testing. C. F. Christopher. (*Amer. Found. Soc., Preprint*, 1956, No. 171). The results of Charpy impact tests carried out on 23 casts of steel over the range 600–1425° C are presented and discussed in relation to the problem of hot-tearing. All the steels showed a sudden decrease in fracture energy at a temperature close to the solidus, the fracture becoming intercrystalline in nature. This brittleness is attributed to melting occurring around the grain boundaries. The basic steels retained their ductility to a temperature about 50° C higher than the acid steels of the same carbon content. Metallographic examination of specimens quenched after heating or cooling into the brittle range confirmed that the drop in fracture energy was associated with melting at the grain boundaries. It is concluded that hot-tearing of castings can only occur during the period when liquid is present at the grain boundaries.—B. C. W.

Furnace Cracking of an Austenitic Stainless Steel. F. A. Hodierne. (*J. Iron Steel Inst.*, 1957, **185,** Feb., 225–227). [This issue].

Hardening Curves for Commercial Iron. S. I. Gubkin and G. N. Mekhed . (*Izvestiya Akademii Nauk SSSR, O.T.N.*, 1956, No. 2, 132–135). [In Russian]. Hardening curves of iron under two forms of loading, uniaxial stretching and torsion, were determined. Curves for hardening on torsion were obtained for the temperature range 20°–1200° C at 100° intervals. Curves for hardening on stretching were determined at 20°, 100°, 200°, and 300° C. The composition of iron and method of determination are described and uses of the methods are discussed.—V. G.

Prestressing an Ultra High-Strength Steel to Perform Even Higher Duty. J. W. Kaufman. (*Metal Progress*, 1956, **69,** May, 87–90). The technique used for the mechanical prestressing of a steel bomb hook which had the necessary static strength, but had not a satisfactory fatigue resistance is described. The hook was stressed in such a way that only the surface metal was deformed in the region, where fracture in service tended to start. Prior to treatment the hooks failed after 5000 alternations, whereas after prestressing the same hooks would withstand 25,000 cycles.—B. G. B.

Hardening of Ferro-nickels Near to Ni_3Fe by Cold Work, and Superstructure. E. Jossa and X. Waché. (*Compt. Rend.*, 1956, **242,** April 16, 1984–1986). A note on the disorder–order transformation, which produces hardening in this material.

Residual Stress in Cold-Drawn Steel Tubing II. H. Imai. (*Tetsu to Hagaue*, 1956, **42,** Feb., 99–105). [In Japanese]. The effects of reduction of outside diameter, die angle, wall thickness, etc. on residual stress were determined for sinking and plug drawing methods. A moderate reduction of outside diameter and sufficient reduction of wall thickness are required to give tubing with low residual stress.—K. E. J.

The Strain-Age Hardening of Mild Steel. B. B. Hundy. (*Metallurgia*, 1956, **53,** May, 203–211). The effects of strain ageing on the mechanical properties of mild steel are reviewed and a modification of the dislocation theory of strain ageing to cover the change in strength and ductility during ageing is discussed. A reduction in the nitrogen content (to below 0·002%) would improve mild steel from the point of view of ductility but it would still be subject to a pronounced return of the yield point on ageing. (40 references).—B. G. B.

Influence of Grinding Fluids upon Residual Stresses in Hardened Steel. H. R. Letner. (*Steel Processing*, 1956, **42,** Jan. 25–29). A ball-bearing type steel was used. Stresses were little changed by aqueous solutions or miscible oils, but some reduction in stress was observed with straight grinding oils. Lubrication appeared to be more important than cooling.

The Investigations of Strain-hardened, Low-carbon, Manganiferous Structural Steels after Annealing. I. Technology and Strength Determinations. F. Erdmann-Jesnitzer. (*Neue Hütte*, 1956, **1,** July, 400–413). Lattice changes due to strain ageing and the reduction, at high temperatures, of embrittlement and strain hardening are discussed.—L. J. L.

Autocorrelation Analysis of the Sliding Process. E. Rabinowicz. (*J. Appl. Phys.*, 1956, **27,** Feb., 131–135). A simple model of the sliding process has been developed in which the junctions are of the same size but have different shear strengths. Using an artificially obtained friction trace it has been shown that the size of the junctions can be deduced through a simple autocorrelation analysis.—E. E. W.

The Strain Ageing of Boron-treated Low-carbon Steels. E. R. Morgan and J. C. Shyne. (*J. Iron Steel Inst.*, 1957, **185,** Feb., 156–160). [This issue].

Metal Fatigue. (*Usine Nouvelle*, 1956, **12,** Feb. 2, 83–87). After a general examination of the subject, the influence of the absolute dimensions of the object subjected to fatigue, and the role played by welds, are discussed. Testing and its usefulness are considered.—T. E. D.

Comet Fuselage Fatigue Tests.—New Water Pressure Tank at Hatfield. (*Engineering*, 1956, **181,** Jan. 6, 18–19). A description is given of the new testing tank at the de Havilland Aircraft Co. Ltd. at Hatfield. The tank is 140 ft long, 20 ft wide and 16 ft deep, has a water capacity of 290,000 gallons.

A Device for the Fatigue Breakage of Metals by an Alternating Sinusoidal Stress at High Frequency. G. Vidal, F. Girard, and P. Lanusse. (*Compt. Rend.*, 1956, **242,** Feb. 20, 986–988). The apparatus can develop a force of 230 kg and can break 4 mm^2 steel test pieces at 6000 Hz.

Resistance of Low-Alloy Steel Plates to Biaxial Fatigue. C. E. Bowman and T. J. Dolan. (*Welding J.*, 1956, Feb., 102s–109s). The relative resistance to repeated loading of several low-alloy steels and a carbon steel are compared. The effect of notches and welds upon the fatigue properties of each material is investigated. It was found that the fatigue strengths of welded specimens were comparable with those for the unnotched plate but the data showed more scatter.

Statistical Representation of S-N Curve on the Fatigue Test Results. M. Kawamoto and T. Nakagawa. (*Mem. Fac. Eng. Kyoto Univ.*, 1956, **18,** Jan., 30–43). [In English]. A statistical approach to results of fatigue-test data is proposed. Without the need to test a large number of specimens at any stress level, the probability of failure can be computed from data at different levels, from consideration of the scatter of any one of three parameters in the stress–number-of-cycles equation. Three sets of results for carbon steel are analysed, as examples.—K. E. J.

Full-Scale Fatigue Tests of Diesel Engine Elements. P. E. Wiene. (*Trans. Inst. Marine Eng.* 1956, **68,** March, 39–59). The paper describes Danish work on springs, crank throws, and piston rods, with experiments on design, material, and assembly. There is a note on laboratory bend tests with the effects of notch sharpness and nitriding. Welded constructions were also tested with reference to stress relief annealing. Further details were given in discussion.

Fatigue Tests on End Closures for Model Headers. P. H. R. Lane. (*Brit. Welding J.*, 1956, **3,** May, 200–205). Pulsating pressure fatigue tests on a number of designs for end closures for 6-in. dia. mild steel pipe are discussed. None of the ends tested had life as great as that of the plain pipe, but four designs gave results which would undoubtedly be satisfactory in service.—U. E.

Influence of Structure on the Electrical Conductivity of Alloys, H. G. Müller. (*Technik*, 1956, **11,** Apr., 275–287). Following a comprehensive survey of literature, the author's investigations of the resistivity of Ni–Fe–Cr alloys are described.—J. G. W.

Attenuation and Permeability of Ferromagnetic Waveguides Between 9000 and 9675 Mc/s. J. Allison and F. A. Benson. (*Proc. Inst. Elect. Eng.*, 1956, **103,** Part C, Mar., 205–211). The attenuations produced in nickel, mild steel, Mumetal, Radiometal, and Rhometal air-filled rectangular waveguides have been measured in the frequency range 9000 to 9675 Mc/s d.c. Resistivities and the effects of surface roughness, temperature and the effect of an external superimposed d.c. field were determined, and permeability/frequency and permeability/temperature curves were drawn. The results are discussed. (30 references).—L. D. H.

Progress in Ultrasonic Examinations. 2. New Techniques and New Equipment. C. W. J. Vernon. (*Welding, Metal Fab.*, 1956, **24,** April, 124–133). A brief review of ultrasonic inspection equipment; some recent applications are described.

Ultrasonic Visual Apparatus and its Use in Non-Destructive Testing of Materials. H. Trommler. (*Arch. Eisenhüttenwesen*, 1956, **27,** Feb., 135–142). Ultrasonic methods permit visual demonstration of internal faults in materials, and the physical principles involved are discussed. The Zeiss apparatus is described. Its main application is to the examination of flat plates. Resolution is claimed to be better than with radiography, and continuous inspection is possible.—A. C.

Ultrasonic Field Inspection Spots Danger Early. R. N. Hafemeister. (*Iron Age*, 1956, **177,** Mar. 22, 88–90). The

use of ultrasonic testing at Allis-Chalmers Mfg. Co., is described. Particular application is inspection of steam turbine studs and bolts in service.—D. L. C. P.

Ultrasonics for the Metal Treater. J. Starr. (*Metal Treating*, 1956, **7**, Jan.-Feb., 10–12). An elementary account, with illustrations.

Ultrasonic Testing of Small-Diameter Tubing with Automatic Recording Equipment. W. L. Fleischmann and H. A. F. Rocha. (*Trans. Amer. Soc. Mech. Eng.*, 1956, **78**, Jan., 211–216). The authors summarize recent progress in the testing of small diameter tubing by automatic recording ultrasonic testing equipment. Cross-sections are presented indicating the type and size of discontinuity detected by this equipment in an 18/10/Nb stainless steel.—D. H.

Non-destructive Sample Testing for Cracks Aids Heat Treatment. F. S. Catlin. (*Metal Treating*, 1956, **7**, Mar.-Apr., 10–13, 28). A number of specific cases are described and illustrated. Magnaflux and Magnaglo equipment was used.

Safety Tests on Railway Signal Posts. (*Instruments in Industry*, 1956, **3**, Apr., 82). The applications of an ultrasonic thickness gauge to railway signal posts in use is described.—L. D. H.

X-Ray Diffraction Helps Control Quality. V. W. Palen. (*Metal Treating* 1956, **7**, Mar.-Apr., 8). Experience with steel and other metal electrical equipment parts is described.

Scattering of X-Rays by Defect Structures. W. Cochran. (*Acta Crystallographica*, 1956, **9**, Mar., 259–262). The intensity of X-ray scattering from a crystal containing defects is shown to depend in a simple way on the Fourier transforms of the defects considered separately.—T. E. D.

Study of Geometrical Imperfections in Monocrystalline Metals. H. Lambot. (*Rev. Univ. Min.*, 1956, 9th series, **12**, Feb., 55–59). The principle of the X-ray technique for the accurate measurement of geometric imperfections in metal grains is explained. Results obtained during the study of deformation and restoration in monocrystalline metals by this technique are given.—B. G. B.

Shortening of Exposure Time for X-Ray Interference Figures by Suitable Arrangement and Shaping of Slits. F. Binder and E. Macherauch. (*Arch. Eisenhüttenwesen*, 1956, **27**, Jan., 67–74). After describing focusing principles the authors refer to the departure from strict focusing with methods used hitherto. Sharp interference lines are obtained on both sides of film by suitable limitation of divergence. The method is exemplified by application to rough crystalline specimens and details of experimental procedure are given.

Reduction of the Effect of Diffuse Radiation. The Study of a Filter and Its Influence. J. Ors. (*Inst. Hierro Acero*, 1956, **9**, Jan.-Mar., 320–324). [In Spanish]. The use of filters and their effect upon the quality of radiographs are discussed. Filters for use with 43 kV. radiation were examined by measuring the relationships I_d/I, for a 1·44 cm thick aluminium specimen; I_d is the diffused and I, the transmitted intensity. I_d/I, was 0·54 without a filter and 0·50 with a copper filter. This figure was reduced to 0·44 by using instead a filter made of four sheets of photograph film as a result of the absorption by the bromide content.

The Temperature Calibration of a High Temperature X-Ray Diffraction Camera. J. A. Brand and H. J. Goldschmidt. (*J. Sci. Instruments*, 1956, **33**, Feb., 41–45). Factors affecting the calibration of the camera, methods of calibrating the thermocouple in position, and for reducing the required correction to a minimum are discussed.—L. D. H.

Application of X-Rays to the Heat Treating Industry. R. E. Ogilvie. (*Metal Treating*, 1956, **7**, Jan.-Feb., 2–5). Diffraction and fluorescence methods are described and examples given.

Radiation Damage in Metals. R. Scimar. *Rev. Univ. Mines*, 1956, 9th series, **12**, July, 185–199). The effect of different types of radiation on the properties of solid materials is considered. The radiations include electrons, gamma rays, neutrons and alpha particles. The mechanical properties of metals are affected as follows: the hardness, rupture strength, elastic limit and modulus of elasticity are increased and the resilience is decreased. No marked influence on creep resistance has been found.—B. G. B.

Heat Transfer. E. R. G. Eckert, J. P. Hartnett, H. S. Isbin, and P. J. Schneider. (*Indust. Eng. Chem.*, 1956, **48**, Mar., Part 2, 655–668). A comprehensive review of more recent developments, with 213 references.

A Variational Principle for the Conduction of Heat. L. G. Chambers. (*Quart. J. Mech. Appl. Math.*, 1956, **9**, June, 234–235).

The Use of Sodium and of Sodium–Potassium Alloy as a Heat-Transfer Medium. W. B. Hall and T. I. M. Crofts. (*Inst. Mechanical Eng.*, 1956, Preprint, pp. 12).

Effect of Stress on the Expansion Coefficient. A. R. Rosenfield and B. L. Averbach. (*J. Appl. Phys.*, 1956, **27**, Feb., 154–156). The experimental technique is described and results are given for expansion tests on specimens of three steels (0·2, 0·4 and 0·8% carbon) and two types of Invar, both under stress and after its removal. When the applied strain is below the elastic limit the expansivity returns to its original value after removal of stress but there is a discontinuous change in the coefficient after applying a stress above the elastic limit.—E. E. W.

Diffusion of Carbon in Iron by Electrolytically Induced Migration in the Presence of Phosphorus. F. Erdmann-Jesnitzer and W. Gunkel. (*Arch. Eisenhüttenwesen*, 1956, **27**, Jan., 41–43). The authors discuss the effect of phosphorus on the migration of carbon in iron during carburization. Experimental apparatus and the preparation of specimens are described. The migration of carbon both in the presence and absence of phosphorus is dealt with.—A. C.

Universal Adapter for X-Ray Apparatus for the Visual Method of Radiography. I. V. Samolov. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 993–995). [In Russian]. An arrangement is described with the aid of which the location of defects is improved and which gives scope for the maximal mechanization of operations in the visual X-ray examination of parts.—S. K.

Some Structural Features of Brittle and Ductile Fractures of Steel. B. S. Kasatkin and B. A. Movchan. (*Izvest. Akad. Nauk S.S.S.R., Otdelenie Tekn. Nauk*, 1956, (**5**), 151–153). [In Russian]. Brittle and ductile fractures of low alloy steel NL2 and Bessemer steel BSt.3 were investigated using an X-ray diffraction method with a narrow field of irradiation (0·15 mm dia.). The results obtained indicated that in brittle fractures a considerable size reduction of the initial grains to a depth of 0·03 (BSt.3 steel) and 0·07 mm (NL2 steel) takes place. The diminution of the initial crystal in a ductile fracture also takes place but to a considerably higher degree.

Construction and Adjustment of a Precision Camera for High Temperature X-Ray Diffraction Measurements. R. Diament. (*Métaux–Corrosion–Indust.*, 1956, **31**, Apr., 167–187). A detailed description of a camera suitable for studying the crystalline properties of materials up to 1000° C *in vacuo* or in a protective atmosphere is given. Examples of the application of the camera are shown.—B. G. B.

The Röntgen Scanning Beam Method. F. Regler. (*Radex-Rundschau*, 1955, Dec., 664–683). A method for the X-ray examination of texture in metal sheets and other fine structures is described and illustrated. The Regler cone and other back reflexion methods are also employed.

Radiographic Study of the Deformation and "Polygonisation" of a Single Crystal of Iron. J. Dejace. (*Rev. Univ. Min.*, 1956, 9th series **12**, Feb., 60–64). The changes occurring in a single crystal of Armco iron by stress and heat have been studied by an X-ray technique.—B. G. B.

Radiography in the Testing of Marine Equipment. W. L. Schwinn and G. R. Forrer. (*Non-Destructive Test.*, 1956, **14**, Jan.-Feb., 32–35). Various types of radiation are discussed together with application and procedure.—A. H. M.

Radiocrystallography. R. Graf. (*Métaux–Corrosion–Indust.*, 1956, **31**, Mar., 148–152). An account is given of an apparatus using a cylindrical monochromator for producing X-rays of uniform geometry for use in the study of the fibrous and orientated structures of metals.—B. G. B.

Characteristics of a Closed-Link Television X-Ray Inspection System. D. Polansky and E. L. Criscuolo. (*Nondestructive Test.*, 1956, **14**, May-June, 18–21). An account of apparatus used for ordnance inspection with typical findings and sensitivities. Both low and high-voltage X-rays can be used and the intensities used can be very low.

An Accurate Method for the Determination of the Thermal Conductivity of Insulating Solids. C. R. Mischke and E. A. Farber. (*College of Engineering, University of Wisconsin, Report No. 5*, 1956, Feb., pp. 1–9). Apparatus is described and results presented. The measurements were made on glass.

Thermal and Electrical Conductivities of Iron, Nickel, Titanium, and Zirconium at Low Temperatures. W. R. G. Kemp, P. G. Klemens, and G. K. White. (*Australian J. Phys.*, 1959, **9**, June, 180–188).

On the Heat-Conductivity of Steels at High Temperatures, I. H. Lange and R. Kohlhaas. (*Forschungsberichte des Wirtschafts- und Verkehrsministeriums Nordrhein-Westfalen*, 1956, No. 263, pp. 37). This is a review of the literature with much tabulated data. (11 references).

Transient Heat Flow. V. Paschkis. (*Amer. Found. Soc. Preprint*, 1956, No. 41). The elementary principles of transient heat flow are outlined and applied to the solidification of metals.—B. C. W.

Recording Linear Expansion during the Prolonged Action of High Temperatures. A. V. Antonovich. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 991–992). [In Russian]. A scheme for recording deformations up to 200 μ and with an accuracy of 2% over prolonged periods is described.—S. K.

Diffusion and Oxidation of Metals. M. T. Simnad. (*Indust. Eng. Chem.*, 1956, **48**, Mar., 586–601). A comprehensive review of all aspects with 271 references.

Measuring the Thermal Diffusivity of Metals at Elevated Temperatures. M. A. El-Hifni and B. T. Chao. (*Trans. Amer. Soc. Mech. Eng.*, 1956, **78**, May, 813–821). The Angström-bar method has been modified and adapted to the measurement of thermal diffusivity (thermal conductivity/specific heat per unit volume) of various plain carbon steels at temperatures in the range 300–1050° F. A small sinusoidal temperature fluctuation is superimposed on the mean temperature of a thin-walled tubular specimen by simultaneous heating and cooling of one end. Thermal diffusivity was calculated from the phase shift and amplitude ratio of the temperature waves determined at two measuring stations.—D. H.

Marker Movement in Scale Layers. K. Sachs. (*Metallurgia*, 1956, **54**, July, 11–17). Nickel and copper markers in the form of electrodeposits and wires of various thicknesses were placed on the surface of mild steel specimens which were subsequently oxidized at 900° C. The results obtained and the various mechanisms which may account for the movement of the markers are discussed.—B. G. B.

The Diffusion Coefficient of Hydrogen in Iron. T. M. Stross and F. C. Tompkins. (*J. Chem. Soc.*, 1956, Feb., 230–234). Measurements, at 150° to 900° C, were made of the rate of evolution of hydrogen into a vacuum from an iron cylinder saturated with hydrogen under various conditions. The results, which indicate that rate-determining processes are absent at the exit-surfaces, are compared with those obtained by a permeation method.—E. E. W.

Problems of Gases in Metals. M. W. Mallet. (*Battelle Tech. Rev.*, 1956, **5**, June, 7–12). The analysis of gases in metals is first explained and then the influence of dissolved gases on metal properties is considered.—B. G. B.

The Effects of Hydrogen in Steel. E. R. Slaughter. (*J. Met.*, 1956, **8**, Apr., 430–431). The author discusses the occurrence of the four principal hydrogen-induced defects in steel, namely porosity, hairline cracks, hydrogen embrittlement, and delayed brittle fracture. The sources of hydrogen are considered.—G. F.

Influence of Vanadium on the Susceptibility to Austenitic Grain Growth. J. Ferrar Flotats. (*Inst. Hierro Acero*, 1956, **9**, Jan.-Mar., 267–276). [In Spanish]. Nine high carbon–chromium steels (about 0·95% C, 1·50% Cr) of different origin were studied to determine their susceptibilities to grain growth. Curves of A.S.T.M. No. from 825° C to 1000° C are given and these are accompanied by micrographs of the initial (at 825° C) grain size and at A.S.T.M. No. 7. Of the four steels containing vanadium (about 0·21%) three showed a lesser and one a greater susceptibility to grain growth as compared with the vanadium-free steels. In the discussion of this paper the author believed this anomaly to lie in the fabrication of the steel.—P. S.

Zirconium in Cast Iron. E. A. Brandler. (*Foundry*, 1956, **84**, June, 100–103). The effect of zirconium in cast iron on graphite type, machinability, sulphur, fluidity, shrinkage characteristics, hardness, and strength are briefly reviewed.

The Influence of Manganese, Chromium and Vanadium on the Surface Tension of Liquid Iron. T. P. Kolesnikova and A. M. Samarin. (*Izvest. Akad. Nauk S.S.S.R., Otdelenie Tekn. Nauk*, 1956, (**5**), 63–69). [In Russian]. Surface tension of iron alloys with manganese, chromium, and vanadium was determined using the method of maximum bubble pressure. The relationship between oxygen content surface tension and non-metallic inclusions was established. Changes of surface tension of molten iron were related to the presence of surface active films of ferrous oxide and variations of the amount and composition of oxidation reaction products of elements introduced into the iron.—V. G.

Pearlitic Cast Irons, Their Load Carrying Properties at Temperatures Between 300° C and 600° C. (*Bradley's Magazine*, 1956, No. 65, 3–4). The effect of alloy additions is mentioned.

Room and Elevated Temperature Mechanical Properties of AISI Type 414 and Type 431 Stainless Steels. E. J. Dulis, S. J. Parker, and P. W. Marshall. (*Trans. Amer. Soc. Metals*, 1956, **48**, 486–508). Tensile properties at room temperature and in the range 700–1100° F, and also creep and creep-rupture properties in the range 900–1200° F were determined for normal and high nitrogen stainless steels. Keyhole-notch transition temperatures were also determined for the normal nitrogen steels.—E. E. W.

Stainless and Heat-Resisting Steels. A. J. Turnell. (*Welding, Metal Fab.*, 1956, **24**, June, 214–216). U.S. specifications and their British equivalents for stainless and heat-resisting steels are compared and modifications are discussed.—U. E.

Enhanced Properties in 17-7 Stainless. M. W. Marshall, D. C. Perry, and N. R. Harpster. (*Metal Progress*, 1956, **70**, July, 94–98). The high strength–weight properties of 17% chromium, 7% nickel, 1% aluminium stainless steel are discussed. The steel is hardened partially by martensitic transformation at − 100° F and further by ageing at 950° F. It is very suitable for use in aircraft or missile parts working up to 800° F. The influence of various forms of heat treatment on the mechanical properties of this steel are given in detail.

The Effect of Vibrations on the Mechanical Properties of H.R. Crown Max and Nimonic C.75. J. Jagaciak and J. W. Jones. (*COA Report*, No. 91, 1955, Sept., pp. 42). The effect of vibrations, sonic and subsonic, during solidification on the mechanical properties of castings of gas turbine materials, with special reference to H.R. Crown Max and Nimonic C.75 was investigated on specially designed test castings. Certain frequencies were found to improve quality, and the effect is attributed to increased density and smaller and more uniform grain size. Theory and experimental methods are discussed and illustrated and results are presented graphically.

An Engineering Approach to some Structural Problems Arising from Kinetic Heating. E. H. Bateman. (*J. Roy. Aeronaut. Soc.*, 1956, **60**, June, 402–407). Stainless steels are considered in regard to thermal effects.

An Industrial Metallurgy Section in the University of Melbourne. H. K. Worner and G. V. Cullen. (*Australasian Eng.*, 1956, **48**, 45–47). British and American research institutions are briefly reviewed, and C.S.I.R.O., and the growth and research projects of the new section are then set out.

METALLOGRAPHY

Standards of Accuracy of the Method of Intercepts. S. A. Saltȳkov. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 949–955). [In Russian]. The accuracy of the method of intercepts in quantitative metallographic analysis is dealt with. The calculation of the number of intercepts, the mean square deviation of this number and the accuracy and reliability of its determination are given detailed consideration.—S. K.

Determination of the Orientation of Micro-Structural Elements. A. G. Spektor. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 955–960). [In Russian]. After a brief consideration of some defects on previous methods for studying the effects of deformation on the structural elements, a refined method is proposed. This is based on the determination of the spatial orientation of the parts of a surface, and, as described, is applicable to structures whose deformation has an axial symmetry such as the drawing, rolling or pressing of circular cross-section parts. The mean orientation of the surface to a given straight line and the normal density function are discussed in detail.—S. K.

Micro-Investigations of Steel in a Magnetic Field. A. N. Chervyakov. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 945–948). [In Russian]. The use of colloidal suspensions of ferro-magnetic materials and magnetic fields to distinguish ferro-magnetic phases in metallographic specimens is described. Details are given of the preparation of the suspension and of the field-producing apparatus. Results for various alloy steels and pure iron are illustrated and compared with ordinary photomicrographs of etched sections.—S. K.

Cinemicrography in the Service of Metallurgy. A. Kerleroux and R. Foin. (*Métaux–Corrosion–Indust.*, 1956, **31**, June, 289–294). Details are given of the photographic techniques used in preparing cinemicrographs for studying crystalline changes during the heat treatment of metals.—B. G. B.

A Few Hints about the Use of the Electron Microscope in Metallurgy. E. Brüche and H. Poppa. (*Metall*, 1956, **10**, May, 415–419). Numerous examples quoted here include the study of surface structure and roughness.—J. G. W.

How is the Metallurgical Microscope Developing ? F. Gabler. (*Metall*, 1956, **10**, May, 427–430). A review of apparatus, with illustrations of polarized light and phase contrast effects is presented. A "television" (flying spot) installation is shown.

A Practical System for Preparing Metallographic Specimens. R. L. Anderson. (*AB Metal Digest*, 1956, **2**, July, 3–8). Polishing machines are advertised.

New Automatic Grinding and Polishing Machine for Metallurgical Specimens. (*Metallurgia*, 1956, **54**, July, 52–53). An illustrated description of a new grinding and polishing machine which can be used for either hand or automatic operation is given.—B. G. B.

The Structure, Deformation, and Fracture of Pearlite. K. E. Puttick. (*J. Iron Steel Inst.*, 1957, **185**, Feb., 161–176). [This issue].

Influence of Elastic Stresses on Recrystallization Textures. H. Stadelmaier and B. F. Brown. (*Z. Metallkunde*, 1956, **47**, Jan., 1–8). The anisotropy of the volume energy of a nucleus being stressed elastically during deformation leads to a minimum value of the nucleation energy for the cube and the [100] fibre texture. The appearance of the cube texture is closely related to strain hardening behaviour during deformation. The article concludes with a mathematical discussion of the free energy of an elastically deformed cubic crystal. (32 references).—L. D. H.

Some Theoretical and Practical Considerations On Recrystallization. J. Bourrat. (*Bull. Cercle Etudes Mét.*, 1956, **7**, June, 19–46). A review of the present state of knowledge of recrystallization phenomena in metals is presented. Primary and secondary crystallization, nucleation, displacement of joints and recrystallized structures are considered. The practical observation of particular crystal structures and textures is also discussed.—B. G. B.

Recrystallization of Austenite at High Temperatures. M. G. Lozinskii and E. I. Antipova. (*Stal'*, 1955, (9), 825–831). [In Russian]. The use of a new method for the investigation of the microstructures of various types of steel heated in vacuum has enabled special features of the austenite recrystallization process to be observed. Experimental determinations have been made of the temperature ranges within which a stepwise growth of austenite grains occurs, and some rules governing austenite recrystallization during isothermal heating have been formulated. The work was based on the microscopical examination of one zone of a polished specimen during its heating, and various microstructures are illustrated. The kinetics of austenite recrystallization was found to depend on the preliminary mechanical and heat treatment of the steel as well as on composition and experimental conditions.—S. K.

The Isothermal Transformation of Lamellar Pearlites to Austenite. M. M. Labib, A. A. Golestaneh, C. Handford, and G. Bullock. (*J. Iron Steel Inst.*, 1957, **185**, Feb., 207–215). [This issue].

Kinetic Study, by Electron Diffraction, of Structural Transformations and Oxidation Processes. Advantages Obtained When Using Various Pressures. J. J. Trillat. (*Rev. Mét.*, 1956, **53**, July, 497–502). A method of continuously recording the diffraction of electrons, during the oxidation of metals, from the metallic surfaces is described. It enables the kinetics of oxidation to be studied at various gas pressures (10^{-3}–10^{-5} mm Hg). The formation of γFe_2O_4 and of FeO during the oxidation of iron has been studied.—B. G. B.

Contribution to the Metallography of Zinc Coatings and Some of their Imperfections. J. Teindl and V. Weniger. (*Hutnické Listy*, 1956, **11**, (3), 160–164). [In Czech]. The nature of commonly occurring faults in hot-galvanized sheet is considered with special reference to recent researches reported in the literature.—P. F.

The Iron–Cementite Diagram. (*Draht, English Ed.*, 1955, Oct., 29–35). A description with an historical introduction discussing the diagram, its constituents, and the effects of heat treatment of carbon steels. The characteristic structures are illustrated.

Low Carbon Martensites. R. H. Aborn. (*Trans. Amer. Soc. Metals*, 1956, **48**, 51–85). This 1955 de Mille Campbell Memorial Lecture is a survey of the nature, properties, and characteristics of low carbon martensites which combine high strength with high toughness and flow resistance with ductility. The basic studies were made on a 0·13% carbon steel and a 0·15% carbon, low-alloy steel but constructional alloy and stainless steels are also considered.—E. E. W.

Effect of Molybdenum in Iron and Steel. A. J. Herzig. (*Metal Progress*, 1956, **69**, June, 72–75). An account is presented of a lecture commemorating the work of William Park Woodside. The influence of molybdenum on hardenability, creep strength, temper brittleness, and machinability of steel and on cast iron is briefly considered.—B. G. B.

The Metallographic Structure of Cast 11–14% Chromium Steels. A. Færden. (*Metallurgia*, 1956, **54**, July, 3–10). Metallographic studies have been made of cast martensitic stainless steels of two series, one with chromium from 11·3 to 14·1% and another with nitrogen from 0·011 to 0·056%. The 14 steels investigated contained from 0·07 to 0·11% carbon and approximately 0·5% nickel. The steels were first studied in the as-cast and tempered conditions and then the austenitic structure was developed by thermal etching in high vacuum. Twenty-one photomicrographs of the various structures obtained are reproduced.—B. G. B.

A Discussion of the Phase Composition of Ball Bearing Steel and its Measurement. D. P. Koistinen. (*Gen. Motors Eng. J.*, 1956, **3**, May-June, 10–13). A modified quantitative X-ray diffraction technique has been developed for determining the phase composition of hardened steels, and a report is given on an investigation into the effects of heat treatment on the hardness of a ball bearing steel using this technique. For comparison the results are given of a similar study carried out on a plain carbon steel. An empirical equation has also been developed for austenite % in SAE 52100 steel, which is both easy to evaluate and accurate.—E. A. C.

Activity of Sulphur in Liquid Iron Containing Silicon. R. A. Karasev and A. M. Samarin. (*Izvestiya Akademii Nauk SSSR, O.T.N.*, 1956, No. 3, 170–173). [In Russian]. Results of measurements of the dependence of the activity coefficient of sulphur dissolved in liquid iron on the content of silicon in the solution $\left(f_S^{Si}\right)$ are given. The method used for these from the solutions investigated *in vacuo*. The values of $\left(f_S^{Si}\right)$ measurements was based on rate of evaporation of sulphur obtained for a given silicon concentration were about twice those determined by Morris and Williams. (*Trans. ASM*, 1949, v. 41, 1425–1439).—V. G.

Sulphur in Steel. (*Aciers Fins Spéc. Franç.*, 1956, March, 42–45). The effect of the presence of sulphur in steel is discussed, considering operations such as welding, forging, machining, etc. Rare earth metals have been found successful in suppressing the disadvantages of sulphur. Experiments have also shown that surface sulphurization increases resistance to wear and to seizing of parts so treated.—E. A. C.

Ferromagnetic Domain Nucleation in Silicon Iron. L. F. Bates and D. H. Martin. (*Brit. Elect. Allied Ind. Res. Assoc. Rep.*, 1956, N/T 72, pp. 11).

Solubility of Nitrogen and Formation of Silicon Nitride in Iron–Silicon Alloys. E. T. Turkdogan and S. Ignatowicz. (*J. Iron Steel Inst.*, 1957, **185**, Feb., 200–206). [This issue].

On Plastic Copper–Iron–Phosphorus Alloys. C. Schaarwächter. (*Forschungsberichte des Wirtschafts- und Verkehrsministeriums Nordrhein-Westfalen*, 1956, No. 205, pp. 25). Parts of the equilibrium diagram are given with tables of hardness values, photomicrography, and a list of uses. (10 references).

CORROSION

Corrosion and Corrosion Testing. B. Waeser. (*Werkstoffe Korrosion*, 1956, **7**, May, 256–261). This general review covers a wide field, for it deals with the deterioration of wood, building stone, cement, and concrete in addition to the corrosion of both ferrous and nonferrous metals. (55 references).—J. C. H.

A Simple Graphical Method for Checking the Adequacy of Stress Corrosion Specimen Dimensions Against Stress Concentrations. R. H. Hay. (*Corrosion*, 1956, **12**, Apr., 171t–173t). To aid the avoidance of failure of thin stress corrosion specimens at pin holes and shoulder fillets a simple graphical

method is explained for determining suitable specimen dimensions.—J. F. S.

Effect of Long Cell Action on Local Cells. R. Pope. (*Corrosion*, 1956, **12**, Apr., 169t–170t). Long cell action can alleviate or aggravate corrosion caused by local cells depending on whether the local cell lies in the cathodic or the anodic part respectively of the long cell. Polarization diagrams are used to illustrate these effects.—J. F. S.

Our Present Conception of the Electrochemical Mechanism of Corrosion, Part I. W. Schwarz. (*Metall*, 1956, **10**, June, 513–519). The recent electrochemical theories of corrosion due to Bonhoeffer, Vetter, and Gerischer are outlined.—J. G. W.

Corrosion and Electrochemistry. G. Valensi. (*Z. Metallkunde*, 1956, **47**, Jan., 50–52). This is a contribution to the discussion on the definition of terms concerning chemical and electrochemical corrosion. (18 references).—L. D. H.

A Practical Corrosion Service Program. B. J. Philibert. (*Corrosion*, 1956, **12**, Apr., 174t–176t). The value of a staff corrosion engineer both in preventing and correcting corrosion is advocated. The corrosion engineer's duties involve a wide knowledge of materials and methods of construction and the effective interpretation and dissemination of that knowledge.

Resistance of Materials to Mechanical Corrosion. R. W. Henke. (*Product Eng.*, 1956, **27**, Jan., 194–197). The causes of corrosion taking place in various forms are discussed, and methods of eliminating its occurrence by suitable design features and choice of materials are described.—E. A. C.

The Effect of Corrosion and Abrasion on Some Ferrous Materials. J. Dearden and J. D. Swindale. (*J. Iron Steel Inst.*, 1957, **185**, Feb., 227–234). [This issue].

Evaluation of the Tendency of Stainless Austenitic Steels to Intercrystalline Corrosion. I. L. Rozenfel'd, Z. A. Vrutsevich, E. I. Titkov, and M. V. Beganov. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 934–936). [In Russian]. Six procedures for testing for intercrystalline corrosion were applied to welded and non-welded specimens of a stainless austenitic steel. Boiling in sulphuric acid–copper sulphate gave good results but such solutions acted rather slowly. Anomalous behaviour of the weld-seam metal was studied in further tests. Significant differences were found between the corrosion behaviour of actual welded apparatus and that of test-pieces and this is attributed to welding effects and mechanical stresses. The general conclusion is that a variety of tests should be used.

Methods of Testing Stainless Steels for Tendency to Intercrystalline Corrosion. A. V. Shreider. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 937–940). [In Russian]. Intercrystalline corrosion testing is considered with special reference to the effect of structure and chemical composition. Treated corrosion test results for 607 heats of type 1 Kh 18 N9T stainless steels are plotted against the titanium/carbon ratio, showing that for heats characterized by values of the ratio $\geqslant 5{\cdot}8$ inter-crystalline corrosion can be practically prevented by sufficiently complete combination of the carbon. The zonal nature of tendency to intercrystalline corrosion for steel characterized by the relation $5(C-0{\cdot}03) \leqslant Ti < 5{\cdot}8C$ is shown by results for plates cut from three sheets.—S. K.

Defects in Accepted Methods of Testing for Intercrystalline Corrosion. G. L. Shvarts and Yu. I. Kazenov. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 922–926). [In Russian]. Official standard procedures for testing for intercrystalline corrosion as applied to corrosion-resisting steels intended for the chemical industry are critically examined. Many defects are pointed out and improvements suggested.—S. K.

Methods of Testing Stainless Steel for Resistance to Intercrystalline Corrosion. E. I. Astrov. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 926–930). [In Russian]. Discrepancies between intercrystalline corrosion test results for stainless steels and the service behaviour of the same steels in corrosive surroundings are briefly considered, testing methods are critically discussed and experiments described. The experiments were on heats of a steel with the following composition range: 0·11–0·19% C, 0·80–1·08% Mn, 0·27–0·61% Si, 0·022–0·025% P, 0·015–0·016% S, 17·23–18·70% Cr, 9·54–10·33% Ni, 0 or 0·3–0·68% Ti, 0 or 3·2–5·7 Ti/C ratio. Water-quenched plate specimens were held for various times in boiling solutions of copper sulphate in sulphuric acid with and without hydrofluoric acid. The results obtained are tabulated and compared. Recommendations for further research are made.—S. K.

Methods of Determining the Tendency of Stainless Steels to Intercrystalline Corrosion. A. A. Babakov. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 931–933). [In Russian]. Reasons for the onset of corrosion at grain boundaries in stainless steels are considered with special reference to carbide precipitation from solid solutions. It is concluded that sulphuric acid–copper sulphate solutions are sufficiently corrosive, but unusual service conditions may require more corrosive media. For rapid testing the anodic polarization method is recommended. Reasons for discrepancies between intercrystalline corrosion test results in general and service behaviour are discussed.—S. K.

Corrosion by Sulphuric Acid. J. Bünger. (*Werkstoffe Korrosion*, 1956, **7**, June, 322–330). This is a comprehensive survey, based on published experimental results and on further original work by the author, of the effects of sulphuric acid on Cr–Ni–Mo–Cu steels and on Ni–Mo alloys, specially chosen for their known resistance to this medium. The field studied covers the whole range from room temperature to the boiling point for acids of up to 95% concentration. The best material of all for this purpose proved to be a 70/30 (nominal composition) nickel–molybdenum alloy.—J. C. H.

Corrosion in the Petroleum Industry. N. Boas. (*J. Inst. Auto. Aeronaut. Eng.*, 1956, **16**, Jan., 5–13). After outlining the mechanism of corrosion and the principles of cathodic protection, the author describes briefly the corrosion problems encountered in storage equipment and marine barges.—L. E. W.

Corrosion Problems in Oil Refining. R. M. Robb. (*Australasian Eng.*, 1956, **48**, Apr., 48–53). Theory and practical aspects are outlined and then refinery problems and their solution are discussed.

An Anomaly in Pipe Line Corrosion Diagnosis. L. P. Sudrabin. (*Corrosion*, 1956, **12**, Mar., 99t). Local cells due to corrosion products resulted in rapid pitting and leak formation in what seemed the cathodic length of a pipeline.—J. F. S.

Corrosion of Gasoline Engine Exhaust Valve Steels. C. H. Allen and M. J. Tauschek. (*Corrosion*, 1956, **12**, Jan., 55–62). The corrosive environment which exists round an exhaust valve and contributes to its failure is considered. A laboratory method of evaluating the resistance of valve steels to molten lead oxide is described and used to compare alternative valve materials. Other factors influencing the failure of exhaust valves are briefly discussed.—J. F. S.

Suggested Non-Technical Manual on Corrosion for Water Works Operators. L. B. Hertzberg. (*J. Amer. Water Works Assoc.*, 1956, **48**, June, 719–738). The basic principles of corrosion theory and of corrosion control are explained. Particular emphasis is given to methods of minimizing the corrosion of underground water pipes.—B. G. B.

A Bibliography of Corrosion by Chlorine. N.A.C.E. Technical Unit Committee T–5A. (*Corrosion*, 1956, **12**, Mar., 141t–148t).

Collection and Correlation of High Temperature Hydrogen Sulfide Corrosion Data. G. Sorell and W. B. Hoyt. (*Corrosion*, 1956, **12**, May, 213t–234t). Corrosion by gas mixtures containing hydrogen sulphide at elevated temperatures is reviewed, with emphasis on catalytic reforming and desulphurizing of petroleum products. Summary curves showing corrosion rates as a function of temperature and hydrogen sulphide concentration are presented as a guide for equipment design. Chromium–molybdenum alloy steels are no more resistant than plain carbon steel, 12% chromium steels are a little better, and 18 Cr–12 Ni steels possess excellent resistance. Aluminium coatings are valuable. The nature and mechanism of hydrogen sulphide corrosion are discussed. Sixty-nine published and 17 unpublished sources of information are quoted and abstracts given of the most important.

Sulphur Dew-Point Corrosion in Exhaust Gases. R. L. Coit. (*Trans. Amer. Soc. Mech. Eng.*, 1956, **78**, Jan., 89–94). Corrosion tests are described in which it was found that the effects of sulphur dew-point corrosion can be minimized by (*a*) the use of Hastelloy C, Carpenter No. 20 or 25/20 stainless steel types of alloy, (*b*) the use of low-sulphur fuels; or (*c*) the maintenance of surface temperatures above the acid–water dew-point. The tests indicate that none of the available coating materials can provide adequate low temperature corrosion protection for heat exchange surfaces or compressor blading.—D. H.

Integration of Corrosion Control in Pier Substructures. C. R. Johnson. (*Corrosion*, 1956, **12**, Apr., 157t–160t). Details are given of the cathodic protection given to three large piers consisting of H-piles driven to rock in the Hudson River. The impressed current systems used were included in the original design of the structures. Provision is made for an

alarm system to operate if the current in any circuit drops below 50 amperes. Unprotected and protected control piles have been driven to permit a check to be made on the effectiveness of the protection.—J. F. S.

An Application of Cathodic Protection to the Inside of a Tank. J. H. Graves. (*Corrosion*, 1956, **12**, May, 254t–256t). A 10,000 barrel steel tank used since 1931 for temporary storage of crude oil suffered internal corrosion of the tank bottom and lower sides within eight years. A coal-tar coating and steam coils slowed down but did not prevent leaks forming after a further twelve years. Magnesium anodes placed inside the tank and covered with water have prevented further trouble very cheaply.—J. F. S.

Corrosion Prevention Practice. IV. Protecting a Tanker. (*Corrosion Prevention and Control*, 1955, **2**, June, 40–41). A brief description is given of the anti-corrosive measures introduced in the cargo tanks of the M.V. *Shell Welder*. The methods used are (*a*) Tank No. 1—Epikote Based Paint, (*b*) Tanks No. 2 and 3—Cathodic Protection, and (*c*) Tank No. 4—Metal Sprayed Coating.—L. E. W.

Corrosion Inhibitors. H. Fischer. (*Z. Metallkunde*, 1955, **46**, May, 350–357). A general survey is given of the nature of metal corrosion inhibitors; the mechanism of inhibition in various corrosion processes is discussed, and the relation of inhibition to the type of metal and its surface is dealt with. (27 references).—L. D. H.

ANALYSIS

Particle Size Analysis and Centrifugal Sedimentation. R. Johnson. (*Trans. Brit. Ceram. Soc.*, 1956, **55**, Apr., 267–285). Factors causing the results of centrifugally assisted sedimentation to differ from those expected are suggested after tests on clay slips. Size comparisons of fine materials can be made in limited circumstances.—D. L. C. P.

The Sampling of Ores. P. Gy. (*Z. Erz. Met.*, 1955, **8**, Special No. B199–B220). A comprehensive account is given in four sections; first, the derivation of formulæ for the minimum sample weight; second, errors involved as the weight is not unlimited as assumed in part 1; third, sampling of noble metals and precious minerals where application of the formulæ is not permissible; and fourth, application to coal, classified or not. Curves are given for practical sampling purposes.

Determination of Iron in Iron Ores and Sinter with the Aid of Trilone B. Yu. I. Usatenko and L. I. Mikhailova. (*Zavodskaya Laboratoriya*, 1955, **21**, (10), 1168–1169). [In Russian]. Based on the observation that in the *p*H range 1–3 stable complexes of tervalent but not bivalent iron are formed with Trilone B, a method for iron determination in ores and sinters has been developed. The hydrochloric acid solution of the sample is neutralized with ammonia till hydroxide precipitates when 1–2 drops of acid are added to dissolve the precipitate. After dilution and addition of 3 drops of sulphosalicylic acid as indicator the solution is titrated with Trilone B solution till the reddish-violet colour changes to lemon-yellow. Calcium, magnesium, manganese, aluminium, and silicic acid do not interfere.—S. K.

A Quick and Precise Heterometric Determination of Iron with Aluminon in Excesses of Foreign Metals. M. Bobtelsky and A. Ben-Bassat. (*Anal. Chim. Acta*, 1956, **14**, May, 439–445.)

On the Determination of Boron in Steels. R. Suarez Acosta. (*Inst. Hierro Acero*, 1956, **9**, 70–74. *Special Number*). [In Spanish]. A variation of the quinalizarin colorimetric method is described. The calibration curve for boron contents between 0·001 and 0·005% is given, determined by using a sulphuric acid solution of a boron-free carbon steel as a basis solution for boric acid additions. This method gives greater accuracy and reproducibility. The procedure for the determination of boron in steel is detailed and methods for the prevention of interference by other elements are discussed. For higher boron contents an aliquot is used. (19 references).—P. S.

A New Method for the Rapid and Accurate Determination of Graphite and Graphitic Carbon in Pig Iron, Grey Iron, and Malleable Iron. R. Kraus. (*Giessereitechn.*, 1956, **2**, June, 141–143). Filtration and combustion of undissolved fractions containing carbon are carried out in porcelain "filter and combustion sleeves" which simplifies and shortens filtration, washing, drying, and carbon determination. The graphite content can thus be determined more rapidly and more accurately than by conventional methods. The filter and combustion sleeves have also been used successfully for silicon determination in iron and steel, and for nickel and cobalt determinations.—L. J. L.

The Determination of Cobalt in Highly Alloyed Steels and Magnet Alloys. F. Cassy. (*Chem. Indust.*, 1956, Apr. 28, 305–307). A description is given of a satisfactory potentiometric method with an accuracy of ± 1%. A study of interference by manganese resulted in the adoption of phenylthiohydantoic acid to separate the cobalt from both manganese and chromium.—E. E. W.

The Determination of Nickel, Cobalt, Chromium, and Manganese by Flame Photometry. F. Burriel Martí, J. Ramírez Muñoz, and M. C. Asunción Omarrementería. (*Anal. Fís Quím.*, 1956, **32(B)**, Apr., 221–236). [In Spanish]. The application of flame photometry to the estimation of these elements in steel is discussed, and the techniques used by the authors are described. The spectra of these elements in the region of 300–500 mμ is given and their interference with each other, and with iron, was studied. Nickel and iron have the greatest influence on accuracy and must be determined separately. When these elements are removed, correction curves enable the remaining elements to be assayed accurately in each other's presence. (15 references).—P. S.

A Precise Direct Heterometric Determination of Traces of Copper with Diethyldithiocarbamate in Excesses of Metals. M. Bobtelsky and R. Rafailoff. (*Anal. Chim. Acta*, 1956, **14**, June, 558–567).

Colorimetric Determination of Phosphorus and Arsenic in Steels. M. Jean. (*Anal. Chim. Acta*, 1956, **14**, 2, February, 172–182). [In French]. A study has been made of the formation and reduction of phosphomolybdic acids at normal temperatures in the presence of bismuth, zirconium and titanium ions. Zr and Ti act as catalysts for the reduction of both phospho- and arseno-molybdic acids whereas Bi reduces only the former acid. Methods are given for the determination of phosphorus and arsenic in steels using these properties.—E. E. W.

Determination of Rare Earths in Steel. H. Krapp. (*Arch. Eisenhüttenwesen*, 1956, **27**, Feb., 103–105). After a short discussion of the fluoride, peroxide, and oxalic acid methods, two modified operations for the determination of rare earths are described. The utility of the method with alloy steels is considered.—A. C.

A Contribution to the Colorimetric Method of Determining Tin. J. Michal and J. Doležal. (*Chemické Listy*, 1956, **50**, (6), 911–915). [In Czech].

The Preparation, Detection, and Separation of Some Valency States of Vanadium and Cobalt by Paper Chromatography. H. M. Stevens. (*Anal. Chim. Acta*, 1956, **15**, July, 51–57). The method is primarily biochemical.

Polarographic Behaviour of Metals in Ethanolamines, I. Iron. R. S. Subrahmanya. (*Proc. Indian Acad. Sci.*, 1956, **43A**, Feb. 133–147). A full account is given with the effects of *p*H and additions of sodium acetates, carbonate or hydroxide or of ammonium chloride and hydroxide, all three ethanolamines were investigated. Two ferric and three ferrous complexes are indicated.

Polarographic Half-wave Potentials of Metal Ions in Various Supporting Electrolytes, I. J. W. Grenier and L. Meites. (*Anal. Chim. Acta*, 1956, **14**, May, 482–494).

Analyses Using Manganese (III) Phosphate II, III. K. Tanino. (*Rep. Sci. Res. Inst.*, 1956, **32**, Mar., 20–23; 24–26). [In Japanese]. The preparations, stability, and oxidizing power of the reagent and its use in the rapid determinations of ferrous oxide in acidic slag are described.

The Analytical Uses of Silver Manganate. V. Complexiometric Determination of Combustible Sulphur as Manganese Sulphate. J. Körbl and R. Přibil. (*Chem. Listy*, 1956, **50**, (2), 232–235). [In Czech].—P. F.

Quadrivalent Uranium as a Reducing Agent in Potentiometric Titrations. I, Estimation of Ferric and Ceric Salts. I. M. Issa and I. M. El Sherif. (*Anal. Chim. Acta*, 1956, **14**, May, 466—473).

Detector for Hydrogen Penetrating Steel. J. O. McCaldin. (*J. Appl. Phys.*, 1956, **27**, Mar., 307). With increased sensitivity, Norton's method of detecting hydrogen penetration permits continuous monitoring during electroplating and chemical cleaning treatments.—E. E. W.

An Apparatus for Differential Thermal Analysis. J. G. Brady, R. L. Eager, and J. M. Humphrys. (*Canad. J. Tech.*, 1956, **34**, Jan., 1–9). An apparatus which has been

used to determine the mineralogical composition of Saskatchewan clays and volcanic ash is described together with some of the results obtained.—B. G. B.

The Construction and Operation of a Molybdenum Wound Laboratory Tube Furnace for Use up to 1850° C, for Use with any Atmosphere. E. S. White. (*Instrument Practice*, 1956, **10**, Apr., 309–313). The construction and operation of a molybdenum-wound tube furnace to work at temperatures of at least 1850° C, with a possible limit of 1950° C. An impervious alumina work tube is used, the winding tube being of impervious alumina for temperatures above 1700° C; otherwise clay bonded fused alumina is recommended. The molybdenum winding is protected from oxidation by an atmosphere of dry hydrogen or cracked ammonia.—L. D. H.

Industrial Application of Spectrographic Analysis. H. Svejda. (*Maschinenwelt Elektrotechnik*, 1956, **11**, Feb., 40, 41–43). A brief outline is given of the principles of spectrography and its applications to industry.—L. D. H.

Spectrography within the 600–900 mμ Range. V. Gazzi. (*Met. Ital.*, 1956, **48**, Jan., 3–7). [In Italian]. The author stresses the usefulness of the spectral region of the greatest wave lengths which it is possible to record on a photographic plate. The arc is shown to be the most suitable source.

Spectrographic Standard Samples of Stainless Steel. (*National Bureau of Standards, Tech. News Bull.*, 1956, **40**, Jan., 5–6). Six new samples are available from the Bureau.

Light Absorption Spectrometry. M. G. Mellon and D. F. Boltz. (*Analy. Chem.*, 1956, **28**, Apr. Part II, 559–576). The literature on absorption spectrometry for the period Aug. 1953 to Aug. 1955 is surveyed. Methods for metals are tabulated and include determination of aluminium in iron, steel, and titanium alloys, cobalt in steel and ores, chromium, copper, manganese, molybdenum, lead, tin, tantalum, vanadium, and tungsten in steel, iron in steel and aluminium alloys, and titanium in iron and steel. Methods for non-metals are similarly tabulated, and include the estimation of nitrogen, phosphorus and silicon in steel.—T. E. D.

Generalities on Spectrocolorimetric Analysis. Some Applications to Iron and Steel. E. Sory. (*Chimie Analy.*, 1956, **38**, Apr., 125–129). The various chemical and physical methods are discussed. Reagents used in the analysis of iron and steel, and the conditions under which they can be used, are examined. Determination of nickel, manganese and molybdenum are studied.—T. E. D.

Spectrochemical Analysis of Grey and White Cast Iron. C. G. Carlsson. (*Jernkontorets Ann.*, 1956, **140**, 2, 137–147). [In English]. Experiments have shown that direct determination of silicon contents of up to 3·5% in cast iron is possible, with an accuracy of $\pm$ 1·0 – 1·5% in white, and $\pm$ 1·0 – 2·0% in grey structures, using the same working curve. The results were achieved with a 220V triggered a.c. spark and a Hilger medium spectrograph equipped with a simple recording device. Important factors were observed to be the fineness of the specimen surface and its temperature.

Some Sources of Error in the Spectrographical Analysis of Steels. B. Morello. (*Met. Ital.*, 1956, **48**, Jan., 15–20). [In Italian]. The application of absolute methods of spectrographical analysis is influenced by different factors, the most important of which are the variability of the equipment and differences in the sensitive materials. The effects of these two factors have been studied quantitatively under specified experimental conditions. Such errors as are attributable to the degree of finish of the discharging surface and to the thermal treatment of the sample have no influence on the analytical data. (22 references).—M. D. J. B.

Spectrophotometric Determination of Iron in Strong Alkali Media. A. A. Schilt, G. F. Smith, and A. Heimbuch. (*Analy. Chem.*, 1956, **28**, May, 809–812). 4:7-Dihydroxy-1:10 phenanthroline (Snyder's reagent) is used as organic ligand in the ferroin chelation with iron (II) in a new procedure for the spectrophotometric determination of iron as a trace element.—T. E. D.

Studies on the Rapid Method of Determination of Iron in Aluminium (III). J. Seki and S. Kitahara. (*Rep. Sci. Res. Inst.*, 1955, **31**, Nov., 423–429). Copper is removed as oxide and iron titrated with $KMnO_4$.

Polarographic Behaviour of Metallic Complexes with Pyrophosphate. Part I. Iron. R. S. Subrahmanya. (*J. Indian Inst. Science*, 1956, **38**, Section A, Apr., 87–95). Using sodium pyrophosphate as the complexing agent a systematic study has been made of the polarographic behaviour of iron. A combination of potassium nitrate with gelatin is suggested for estimating iron polarographically in the presence of pyrophosphate.—B. G. B.

Colorimetric Determination of Nitrogen in Steel. E. J. Dubox and A. M. Mayozal. (*Anal. Asoc. Quim. Argentina*, 1955, **43**, Dec., 227–237). Experiments with different acids and different volumes of alkali solution are described and a standard procedure is established. Sulphuric acid, 30% NaOH and Nessler Reagent are used, and an ordinary 500 ml distilling flask and condenser.

Amperometric Determination of Manganese and Molybdenum in Ferromanganese and Ferromolybdenum. N. M. Degterev. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 917). [In Russian]. The amperometric methods briefly described give considerable saving of time in determinations of manganese and molybdenum in the corresponding ferro-alloys, the mean error being 1–2%.—S. K.

Polarographic Determination of Niobium and Titanium in Sulphuric Acid Solutions. E. I. Krylov and V. S. Kolebatova. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 911–913). [In Russian]. The practicability of polarographic determinations of niobium and titanium using sulphuric acid solutions and a photo-recording micropolarograph of the Heyrovsky pattern has been demonstrated.—S. K.

Determination of Titanium by Cupferron with Complexone III as the Masking Agent. A. K. Majumdar and J. B. R. Chowdhury. (*Anal. Chim. Acta*, 1956, **15**, Aug., 105–108).

Colorimetric Ferrodipyridyl Method for the Determination of Vanadium in Iron Ores. A. I. Ponomarev and L. L. Ratina. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 918). [In Russian]. In the method briefly described, vanadium in the tetravalent state reduces iron from the ferric to the ferrous state, the latter being determined colorimetrically in the form of the intensely red complex $[Fe(C_{10}H_8N_2)_3]^{+2}$.—S. K.

Devices for Automatic Potentiometric Titration. R. Audran, D. T. R. Dighton. (*J. Sci. Instruments*, 1956, **33**, Mar., 92–95). Two devices, each controlling an electromagnetically operated burette tap, operated from the output of a suitable electrode, are described.—L. D. H.

Analytical Applications of the Chemical Action of Light. II. New Volumetric Determination of Uranium VI through Photochemical Reduction by Lactic Acid. G. G. Rao, V. P. Rao, and M. V. R. Rao. (*Anal. Chim. Acta*, 1956, **15**, Aug., 97–101).

Diallyldithiocarbamido-hydrazine as an Analytical Reagent. II. Determination of Copper, Zinc and Nickel in the Presence of Iron and Uranium. N. K. Dutt and K. P. S. Sarma. (*Anal. Chim. Acta*, 1956, **15**, Aug., 102–104).

Electron Diffraction. Its Application to Chemical Analysis. B. S. Cooper and H. E. Bullen. (*G.E.C.J.*, 1956, **23**, July, 130–136). A camera and its operation are described with a short account of practical applications.

The Hydrolysis of Ferrous Chloride at 25°. K. H. Gayer and L. Wootner. (*J. Amer. Chem. Soc.*, 1956, **78**, Aug. 20, 3944–3946).

Zone Melting Process Aids in Producing Pure Materials. (*Indust. Heating*, 1956, **23**, Feb., 264–266, 440). Apparatus constructed at U.S. Bureau of Standards for purification of small quantities of metals is described.—A. D. H.

Rapid Chemical Analysis with X-ray Spectrograph. A. M. Reith and E. D. Weisert. (*Metal Progress*, 1956, **70**, July, 83–87). The successful commercial use of X-ray fluorescence analysis for the routine analysis of iron-, cobalt-, and nickel-base alloys is described. The results obtained, techniques developed, preparation of standards, and the accuracy of the method are explained.—B. G. B.

Use of the Spectrograph in Fabrication Shops. H. E. Boyer and F. E. Fitzgerald. (*Iron Steel*, 1956, **29**, Feb., 65–69; Mar., 99–103). A detailed description is given of the principles and operation of the spectrograph, and its limitations and advantages are discussed. The steps which are necessary in establishing a complete spectrographic set-up are summarized.—G. F.

Russians Use Tagged Isotopes to Study Steelmaking. (*Metal Progress*, 1956, **69**, June, 62–65). A number of examples of the use of radioactive isotopes in the Russian iron and steel industry are briefly described. They include the study of: the movement of materials in the blast furnace, sulphur partition between slag and metal, mixing of metals in the open hearth and electric furnace, cold metal melting, dephosphorization in the open hearth furnace and inclusions in steel ingots.—B. G. B.

Nuclear Technology and Metallurgy. K. Lintner and E. Schmid. (*Metall*, 1956, **10**, May, 373–387). A general survey of the use of nucleonic techniques in metallurgical investigations, of irradiation to bring about changes in metals, and of the metallurgy of nuclear reactors. Examples quoted include pig iron analysis, wear tests of tool steels, study of phase and structural changes in Armco iron and nickel steel, crystallographic analysis of the cobalt–iron and nickel–iron systems; effect of radiation on the mechanical properties of α-iron and various steels. (99 references).—J. G. W.

Radio-active Isotopes for Testing Cutting Tools and Cutting Fluids. (*Machinery Lloyd, European Edn.*, 1956, **28**, Sept. 8, 55–57). An account of the work by Messrs. Alex. Duckham and Co. with a note on safety precautions is given. (*See also Atomics*, 1956, **7**, July, 229–232).

Use of Radioactive Isotopes for Measuring Liquid Levels. L. K. Tatochenko and S. V. Medvedev. (*Zavodskaya Laboratoriya*, 1955, **21**, (10), 1188–1192). [In Russian]. Descriptions are given of apparatus developed in the U.S.S.R. for the determination of the levels of fused metals and other liquids with the aid of radioactive isotopes. The types suitable for liquid-metal level indication are IU–2, IU–2a, and IU–3. The first two are indicators, but the IU–3 instruments can be used for automatic recording and level-control. All are of the gamma-ray type, the source being ^{60}Co. Halogen counters are used with all except the IU–2.—S. K.

The Basis for Standards for Radiation Protection. L. S. Taylor. (*Non-Destructive Test.*, 1956, **14**, Jan.-Feb., 10–15, 40). The author deals with the history of standards of radiation protection and gives a background survey of the integrated dose, exposure of population groups, and the disposal of radioactive waste.—A. H. M.

INDUSTRIAL USES AND APPLICATIONS

How to use Steel Effectively in Machinery. O. Blodgett. (*Welding J.*, 1956, **35**, April, 311–318). Certain rules of thumb are presented and short cuts developed during recent years. The following are discussed: rules for bending, rules for twisting, and torsion.—U. E.

Case-Hardened Nickel–Chromium Steel Solves Aircraft Gear Problem. (*Inco Nickel Topics*, 1956, **9**, (5), 11). Carpenter No. 158 alloy was used for small gears.

Adopting Nickel Alloy Steel Gearing Stops Excessive Rejects. (*Inco Nickel Topics*, 1956, **9**, (5), 1, 5). Nickel–molybdenum steels of types 4620 and 4635 are used.

New Alloys for Automotive Turbines. D. N. Frey. (*Foundry*, 1956, **84**, June, 108–111). The economics of using high temperature alloys in an automobile gas turbine are briefly reviewed and the properties of the iron base chromium–manganese–nitrogen austenitic alloys, the iron–aluminium ferritic alloys containing up to 16% aluminium, and the cast ferritic alloys with up to 12% chromium are summarized.

Heat Resisting Steels and Alloys in the Manufacture of Small Gas Turbines. (*Aciers Fins Spéc. Franç.*, 1956, March, 60–63). Details are given of the composition and characteristics of some of the special materials developed for use in the manufacture of gas turbines. Examples are given of their application in such turbines.—E. A. C.

Manufacture of Magnetic Materials. (*Machinery Lloyd, European Edn.*, 1956, **28**, Sept. 8, 66–67). A description of the Telegraph Construction and Maintenance Co., Ltd., Crawley works.

The Increasing Importance of Steel for Mine Extension Purposes. H. U. Ritter. (*Glückauf*, 1956, **92**, June 9, 646–652). The increasing substitution of steel for wood in pit construction is described in detail, and the economic implications are discussed.—L. D. H.

Stainless *vs.* Titanium for High Speed Aircraft. R. G. Sloan. (*Mat. Methods*, 1956, **43**, Apr., 124–127). Charts of mechanical properties are given for 17–7 PH stainless steel, C–110–M and 6Al–4V titanium alloys and commercial annealed titanium, and 7075–T6 and 2024–TS6 aluminium alloys. Tensile strengths, creep properties, and similar values are shown graphically against density.

HISTORICAL

Golden Anniversary of American Electric Steel-Making. (*Steel Processing*, 1956, **42**, May, 282, 293). An account of the furnace installed by Heroult for the (then) Halcomb Steel Co. in 1906.

Commemorative Dates in 1956. (*Stahl u. Eisen*, 1956, **76**, Jan. 12, 39–41). Notable people and events of 1556, 1706, 1756, 1781, 1806, 1831, 1856, 1881, and 1906 are briefly mentioned.

Francis Bourdon, Father of the Power Hammer and the Forging Press. (*Aciers Fins Spéc. Franç.*, 1956, March, 125–129). Francis Bourdon (1797–1867) was regarded as one of the leading engineers of his time, and among his many remarkable achievements in almost every branch of engineering two were outstanding, the design and construction of the first steam hammer for heavy forging (1841), and the first hydraulic forging press (1852).—E. A. C.

Darlaston Iron-works. (*Bradley's Magazine*, 1955, (Winter), 3–6). The history of the Darlaston Green Furnaces is traced back to the seventeenth century and the development of the ironworks through the years is described.—M. A. K.

ECONOMICS AND STATISTICS

Pig-iron and Steel. (*Found. Trade J.*, 1956, **100**, Jan. 12, 49–51). The production of iron and steel in Great Britain in 1955 is reviewed together with the price structure and raw material supply position of the industry in the same period.

Statistics: Development, Present State and Applications in the French Steel Industry. (*Aciers Fins Spéc. Franç.*, 1956, March, 14–21). A brief historical account is given of the origin of statistics and the development of probability calculus. Two practical applications are described, and a reference is also included to the various institutions available in France for courses of instruction in the application of statistics.

Brazilian Production of Ferro Alloys and Steels. (*J. Four. Elect.*, 1956, **65**, May-June, 83). Steel production in 1955 was 1,200,000 tons. The production of ferromanganese, ferro-silicon, and silicon–manganese in 1955 was 8250, 4250, and 3100 tons respectively. A list of the most important metallurgical companies is given.—B. G. B.

Metal Working in Canada. H. McLeod. (*Canad. Metals.* 1956, **19**, May, 8–28). Statistics showing the output of Canada's metal-working industries up to 1955 and estimates for 1956 are presented in detail. Pig iron production was 3,213,000 tons and steel ingots 4,442,000 tons for 1955—both a record.—B. G. B.

The Canadian Steel Industry. (*Metal Bull.*, 1956, Sept. 11, 11–14). A review of post-war expansion and outlook.

MISCELLANEOUS

Investing in Research. P. Spear. (*J. Inst. Prod. Eng.*, 1956, **35**, June, 363–384). A large number of examples of the successful use of research in industry is discussed. (73 references).—B. G. B.

Research for Small Firms. C. N. Kington. (*ASLIB Proceedings*, 1956, **8**, Aug., 143–154). Special reference is made to cutlery and files.

The Protection of Iron Works Installations against Frost. J. Mikulski. (*Hutnik*, 1955, **22**, (12), 437–444). Simple methods of protecting coke-ovens, blast furnaces, open-hearth furnaces, rolling mill installations, pipes, and instruments against frost are described.—W. E. & A. P. M.

An Introduction to Automatic Control. R. S. Seagrave. (*Instrument Eng.*, 1956, **2**, Oct., 34–39). Elementary concepts are outlined with examples.

Foremanship in Ironmaking. R. Kingston. (*Iron Coal Trades Rev.*, 1956, **172**, June 29, 1093–1104). The author puts forward suggestions upon which blast furnace operators may base their daily and shift programmes, referring particularly to foremen's responsibilities. He discusses in detail the control of the furnace, correction of driving irregularities, and the charging and tapping practice. The importance of an efficient furnace cooling-water service is stressed, and finally the operation of the pig-casting machine is described.—G. F.

A Limited Le Chatelier Principle. H G. Bos. (*Chem. Week.*, 1956, **52**, Aug. 11, 601–607). [In Dutch]. The author formulates in his paper a modified definition of the Le Chatelier principle with a view to meeting the objections appearing nowadays in the literature concerning the shift of reversible reactions in equilibrium when using the Le Chatelier and van t'Hoff principles.—F. R. H.

Progress Report on the Plastic Design of Steel Frames. W. Fisher Cassie, and S. Henderson. (*Brit. Welding J.*, 1956, **3**, June, 241–245). The application of the method of plastic design to steel construction is described.—U. E.

FREEMAN, HENRY G. "*Das Englische Fachwort.*" 7th Edition. 8vo, pp. 498. Essen, 1955: Verlag W. Girardet. (Price DM. 28.80).

Herr Freeman is known to many English metallurgists for his German–English and English–German "Dictionary for Metallurgists," a work of great scope and reliability which has served many translators very well. Translation is, however, something more than a dictionary exercise, and "Das Englische Fachwort" is intended to help Germans to avoid some of the traps set by English usage of technical terms. It is divided into some 120 short passages, either dealing with some real difficulty such as the correct choice, from "machine," "engine" or "motor," for the German word "Maschine" in various applications, or the remarkable fact that "Schraube" can be rendered as "screw" or as "bolt" and that it depends largely on the presence or absence of a "Mutter"—in this case, "nut"—or elaborating upon the English equivalents of the main words in some sector of metallurgical technique, such as "Kaltverformung." A two-language dictionary completes the volume. This is the seventh edition, and the fact that it has grown from 125 to 346 pages (excluding the dictionary section) since 1938 gives proof of the author's determination to master the niceties of the English language.

J. P. S.

NORTHCOTT, L. "*Molybdenum.*" (Metallurgy of the Rarer Metals, No. 5). 8vo, pp. xii + 222. Illustrated. London, 1956: Butterworths Scientific Publications. (Price 40*s*.).

This further addition to the series on the "Metallurgy of the Rarer Metals" is again of considerable value as a reference book. Molybdenum, although widely used for many years as an alloying element has only recently come to the fore as a base metal. The earliest production was all by powder metallurgical techniques, but recent developments have led to the consumable-arc-melting of ingots up to ½ ton in weight. Whilst most of these developments have taken place in the United States, the author has been closely associated with current research on the metal in Great Britain, and accordingly the subject is treated authoritatively and comprehensively.

Adequate treatment is given to the established techniques and facts concerning the extraction, powder metallurgy, arc-melting and fabrication of the metal and its resulting physical and mechanical properties. The literature has been thoroughly reviewed and many references are given, including work published as recently as 1955.

The subject of molybdenum alloys, although a very recent one, is treated at considerable length and the review constitutes a very complete summary of current research. Whether the excellent high-temperature strength of molybdenum can be fully utilized depends on whether means can be found to impart scale resistance, either by alloying or by coating. Despite extensive research in both fields the author is drawn to the reluctant conclusion that these efforts have not so far met with very great success.

Perhaps the weakest section of the book is that on uses, which occupies a mere two pages. One feels, however, that it would be unfair to blame only the author for this, as unfortunately the uses of molybdenum are so far somewhat disproportionate to the efforts made on its research and development in recent years.—H. C. CHILD.

THE PHYSICAL SOCIETY. "*Reports on Progress in Physics.*" Vol. XIX, 1956. Executive Editor, A. C. Strickland. La. 8vo, pp. iv + 367. Illustrated. London, 1956: The Society. (Price 50*s*.).

The high level of content, and the excellent appearance of this volume of the yearly reports has been well maintained. It will be of great value to scientists who wish to keep up with modern physics: though there is not much of interest to the metallurgist, except H. Y. Fan's paper on "Infra-Red Absorption in Semiconductors," it will certainly give him a view of what is happening in many other fields, and an insight into modern physical conceptions.—J. P. S.

TAYLOR, E. R. "*Definitions and Formulæ for Students: Metallurgy.*" Fifth edition. Sma. 4to, pp. iv + 60. Illustrated. London, 1956: Sir Isaac Pitman & Sons, Ltd. (Price 1*s*. 6*d*.).

The Fifth Edition of "Definitions and Formulæ for Students—Metallurgy" by E. R. Taylor is only a slightly modified version of that issued in 1950. It continues to serve its original purpose of providing definitions of metallurgical terms for the large number of people engaged in the metal trades. This booklet has not increased in size, but its additional cost is justified.

Certain new definitions and formulæ have been introduced, mainly in Sections I and VI. Some of the older definitions have been deleted. Section I could be satisfactorily sub-divided to produce sections on Physical Metallurgy, Mechanical and Thermal Treatment, Corrosion and Surface Treatment. In addition, no reference is made to terms employed in metallurgical analysis.

In view of the progress and development of the metallurgical industries, any future editions of this booklet will require considerable revision and expansion.—L. W. DERRY.

NEW PUBLICATIONS

AMERICAN SOCIETY FOR TESTING MATERIALS. "*Symposium on Impact Testing.*" Presented at the Fifty-Eighth Annual Meeting, American Society for Testing Materials, Atlantic City, N.J., June 27, 1955. (ASTM Special Technical Publication No. 176). 8vo, pp. [v +] 170. Illustrated. Philadelphia, Pa., 1956: The Society. (Price $3.50).

AMERICAN WELDING SOCIETY AND ASTM. "*Tentative Specification for Welding Rods and Covered Electrodes for Welding Cast Iron.*" ASTM A 398–56T, ASW A 5·15–56T. La. 8vo, pp. 11. New York and Philadelphia; 1956: The Societies. (Price $0.40).

AMERICAN WELDING SOCIETY AND ASTM. "*Tentative Specification for Surfacing Welding Rods and Electrodes.*" ASTM A 399–56T, AWS A 5·13–56T. La 8vo, pp. 26. New York and Philadelphia; 1956: The Societies. (Price $0.40).

ASSOCIATION DES INDUSTRIELS DE BELGIQUE. "*Compte Rendu Général des Travaux de la Conference Internationale sur les Méthodes Non Destructives pour l'Étude et le Contrôle des Matériaux Organisée à Bruxelles* 1955." 4to, pp. 393. Brussels, 1956: The Association. (Price 700 fr. Belg.).

BAKER, J. F. "*The Steel Skeleton.*" Volume I. "*Elastic Behaviour and Design.*" La. 8vo, pp. xi + 206. Illustrated. Cambridge, 1954: The University Press. (Price 50*s*.). (*See next entry*).

BAKER, J. F., M. R. HORNE, and J. HEYMAN. "*The Steel Skeleton.*" Volume II. "*Plastic Behaviour and Design.*" La. 8vo, pp. xii + 408. Illustrated. Cambridge, 1956: The University Press. (Price 63*s*.). (*See preceding entry*).

BARDIN, I. P., and N. P. BANNYI. "*Ferrous Metallurgy in the Next Five Years.*" [In Russian.] 8vo, pp. 176. Illustrated. Moscow, Leningrad, 1947: Academy of Sciences U.S.S.R., Metallurgical Institute.

BARDIN, I. P., A. E. PROBST, and V. V. RIKMAN. "*Metallurgical Problems of the North-East.*" [In Russian.] 8vo, pp. 144. Illustrated. Moscow, 1946; Academy of Sciences U.S.S.R., Leningrad-Murmansk Expedition.

BENSIMON, R. "*Les Aciers Non Alliés.*" La. 8vo, pp. 192. Illustrated. Paris, 1956: Eyrolles. (Price 1560 Fr.).

BOLKHOVITINOV, N. F. "*Metallurgical and Thermal Problems.*" [In Russian.] Third edition, revised. 8vo, pp. 446. Illustrated. Moscow, 1954: Government Scientific and Technical Publishers of Mechanical Engineering Literature.

BOWDEN, F. P., and D. TABOR. "*Friction and Lubrication.*" Sma. 8vo, pp. x + 150. Illustrated. London, 1956: Methuen & Co., Ltd.; New York: John Wiley & Sons, Inc. (Price 10*s*. 6*d*.).

BRITISH PRODUCTIVITY COUNCIL. "*Iron and Steel.*" Review No. 27. 8vo, pp. 47. Illustrated. London, 1956: The Council. (Price 2*s* 6*d*.).

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BRITISH STANDARDS INSTITUTION, B.S. 1121: Part 25: 1956. "*Methods for the Analysis of Iron and Steel. Vanadium in iron and steel, and ferro-vanadium.*" 8vo, pp. 10. London, 1956: The Institution. (Price 2*s.* 6*d.*).

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ČABELKA, JOSEF. "*Schweissbarkeitsprüfung.*" Pp. 48. Illustrated. Bratislava, 1956: Forschungsinstitut für Schweisstechnik.

COGHLAN, H. H. "*Notes on Prehistoric and Early Iron in the Old World.*" Including a Metallographic and Metallurgical Examination of Specimens Selected by the Pitt Rivers Museum by courtesy of the Director of Research and Technical Development of Messrs. Stewarts and Lloyds, and Contributions by I. M. Allen, Museum Technician. (Pitt Rivers Museum, University of Oxford, Occasional Papers on Technology, 8, edited by T. K. Penniman and B. M. Blackwood. La. 8vo, pp. 220 + 16 Plates. Oxford, 1956: The University Press. (Price 25*s.*).

"*Commemorating the Jubilee of The Thermal Syndicate Limited,* 1906–1956." La. 4to, pp. xiv + 48. Illustrated. [Wallsend-on-Tyne, 1956]: The Company.

"*Continuous Casting of Steel.*" [In Russian]. Report of the First All-Union Conference on Continuous Steel Casting, 17–19 Oct., 1955. La. 8vo, pp. 300. Illustrated. Moscow, 1956: Izdatel'stvo Akademii Nauk S.S.S.R.

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DEUTSCHER STAHLBAU-VERBAND. "*Gestalteter Stahl.*" Part 7, 1955. 4to, pp. 98. Illustrated. Köln: 1955. Stahlbau-Verlag GmbH. (Price DM. 10.50).

"*Le Fer à Travers les Ages. Hommes et Techniques.*" Actes du Colloque International, Nancy, 3–6 Octobre, 1955. (Annales de l'Est, Mémoire No. 16, ouvrage publié avec le concours du Centre National de la Recherche Scientifique). La. 8vo, pp. 592. Illustrated. Nancy, 1956: La Faculté des Lettres de l'Université de Nancy. (Price 1100 fr.).

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HOARE, W. E. "*Tinplate Handbook.*" Facts about Tinplate for Buyers and Users. Third (revised) edition. 8vo, pp. 44. Illustrated. Greenford, Middlesex, 1956: Tin Research Institute.

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"*Pig Irons of Great Britain.*" Ninth edition. Sma. 8vo, pp. [iv +] 29. Birmingham, 1955: Darby & Co. (Birmingham), Ltd.

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W. C. F. HESSENBERG, M.A., F.I.M.

WILFRID HESSENBERG was born on November 14, 1909. He was educated at Bedales School and Emmanuel College, Cambridge, where he graduated with honours in the Natural Sciences in 1931. On leaving university he joined the laboratories of the Enfield Cable Works Ltd. Two years later he transferred to the sister company of Enfield Rolling Mills Ltd., whose new copper refinery and rolling mills had just been completed.

In 1939 he joined the Development Department of the British Non-Ferrous Metals Research Association and was appointed head of that department in 1945. In the summer of 1946 he was seconded for three months to the British Commonwealth Scientific Office in Washington, during which time he made a tour of a number of metallurgical research institutions and non-ferrous metal works in the U.S.A. and Canada. While with the B.N.F.M.R.A., Mr. Hessenberg took a special interest in metal working problems and was a member of the Rolling Mill Research Sub-Committee of the Iron and Steel Industrial Research Council.

In 1947 he joined the British Iron and Steel Research Association as Head of the Mechanical Working Division, and was appointed Deputy Director in January, 1951. He has recently relinquished the former post in order to devote his full time to the Deputy Directorship.

Mr. Hessenberg, who has been a member of The Iron and Steel Institute since 1947, succeeded Sir Charles Goodeve, F.R.S., as Representative of B.I.S.R.A. on the Council of the Institute in 1956, when Sir Charles was elected a Vice-President.

W. C. F. Hessenberg, M.A., F.I.M.

Honorary Member of Council